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SOME COMMENTS ON THE EFFICIENCY OF SIGNIFICANCE TESTS

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1. *Summary*

A METHOD sometimes used to measure the efficiency of a significance test consists in associating a statistic with the test and defining the efficiency of the test to be the efficiency of the statistic considered as an estimate. This paper investigates the power function implications of the estimate method of defining the efficiency of a test for several special cases where uniformly most powerful tests exist.

Of the various ways of defining the efficiency of an estimate, consideration will be limited to one definition for finite sample sizes and to two definitions for the asymptotic case. For finite sample sizes, the efficiency of an estimate is defined to be the minimum variance for such estimates divided by the variance of the given estimate (e. g., see [1, p. 481]). For one asymptotic definition, the asymptotic efficiency of an estimate equals the limiting finite sample efficiency of that estimate as the sample size increases. For the other asymptotic definition, the value of the asymptotic efficiency is based on the variances of certain asymptotic distributions; it is the minimum variance for such distribu-

tions divided by the variance of the asymptotic distribution associated with the given estimate.

Examples are presented which show that an estimate efficiency of $100E\%$ does not necessarily imply that the corresponding most powerful test based on $100E\%$ as many sample values has approximately the same power function as the given test for the admissible set of alternative hypotheses. Some of these examples are asymptotic (for these examples, the two methods of defining asymptotic estimate efficiency are equivalent). However, results are obtained for the asymptotic case which indicate that this power function property does hold for the usual type of significance tests if the pertinent statistics have distributions which are asymptotically normal and the method of defining asymptotic estimate efficiency is that based on the variance of the asymptotic distribution of the estimate. These results do not necessarily hold if the asymptotic estimate efficiency is defined to be the limiting value of the efficiency of the estimate for finite sample sizes.

2. *Introduction and discussion.* As stated in Section 1, the definitions of estimate efficiency considered in this paper are based on ratios of variances. In some cases these variances may not exist because the population means do not exist. In other cases the variances might exist but the ratio is of an indeterminate form (e. g., $0/0$ or ∞/∞). In this paper, however, consideration will be limited to situations which furnish ratios of variances which have determined values.

As the first step of the investigation, let us consider what properties any suitable definition for the efficiency of a significance test should yield.

Intuitively, the efficiency of a test would seem to measure what fraction of the total amount of "information" obtainable from the given sample is utilized by the specified test. This raises the question of what represents the total "information" obtainable from a given sample. For the usual type of situation, the purpose of a significance test is to furnish a means of deciding between the null hypothesis H_0 and some specified set H_1 of alternative hypotheses. Consider the set of tests which are competitive with the test whose efficiency is being considered; i. e., tests of the same hypothesis H_0, based on sample values from the same population, and at the same significance level. Suppose that for the alternatives of H_1 this set contains a test which is uniformly most powerful for every sample size. Then the "information" furnished by applying this most powerful test to the given sample would appear to be

the total amount of "information" obtainable from the given number of sample values. Also the "information" furnished by applying this most powerful test to a sample with size equal to $100E\%$ of the size of the given sample would seem to be a good interpretation of what is meant by a fraction E of the total "information" obtainable from the given sample.

On the basis of the reasoning just outlined, if the set of competitive tests contains a test which is most powerful for H_1 and every sample size, any suitable definition should yield a significance test efficiency which has the property:

(a) The "information" furnished by the given test is approximately the same as the "information" furnished by the corresponding most powerful test based on a sample size equal to the sample size for the given test multiplied by the efficiency of that test.

However, the established method of measuring the "information" furnished by a significance test consists in considering the power function of that test. Thus, given H_1, if two competitive tests are to be thought of as furnishing approximately the same "information," it seems reasonable to demand that their power functions be approximately equal for the alternatives of H_1. In the language of power functions, property (a) can be restated as:

(b) Let us consider a specified set of alternative hypotheses H_1 and a test based on n sample values. An efficiency of $100E\%$ for this test implies that for H_1 the corresponding most powerful test based on nE sample values has approximately the same power function as the given test.

The purpose of this paper is to investigate the estimate method for defining the efficiency of a significance test from the viewpoint of property (b).

Since the value of nE need not be an integer, it is necessary to decide what is meant by the power function of a test based on a non-integral sample size. In what follows the power function of the most powerful test for non-integral values of nE will be obtained from the power function of that test for integral sample sizes by interpolation. For the cases considered in this paper, the power function of the most powerful test can be obtained as an explicit function of the sample size; the

interpolated power function is obtained by direct substitution of nE for the sample size in the power function expression. Although this procedure of determining the power function for a non-integral sample size may not be completely realistic, it does furnish a reasonable approximation to the desired comparison.

Another point to be considered is the meaning of the statements: "Two significance tests have approximately the same power function for H_1," and "Two power functions are approximately equal for H_1." A definition of the word "approximately" which is suitable for all situations appears very difficult to obtain. In certain special cases an area definition has been found to be useful (see [2]). For the situations investigated in this paper, however, it is not necessary to have an exact definition of when two power functions are to be thought of as approximately equal for a specified set of alternatives. In all the cases considered, whether two power functions are approximately the same or not will be obvious on intuitive grounds.

As pointed out in Section 1, for the purposes of this paper the efficiency of an estimate based on a finite size sample is taken to be the greatest lower bound of the variances for such estimates (same parameter estimated and same sample used) divided by the variance of the given estimate. This defines the efficiency of an estimate for every finite sample size n. For asymptotic cases, however, two different methods for defining the efficiency of an estimate were chosen for consideration. For one method, the asymptotic efficiency of an estimate is defined to be the limit of the efficiency of that estimate as $n \to \infty$ (see, e. g., [1, p. 489]). The other method is suggested by R. A. Fisher's original definition of the efficiency of an estimate (see, e. g., [3]). Let T be the estimate investigated and consider the asymptotic distribution of $\sqrt{n}(T - \psi)$, where ψ is the parameter estimated by T. The variance of this asymptotic distribution divided into the greatest lower bound of the variances of all asymptotic distributions based on such estimates of ψ represents the asymptotic efficiency of T as defined by the second method. This definition differs from Fisher's definition in that the asymptotic distributions are not required to be normal. Since the limiting variance of $\sqrt{n}\,T$ is not necessarily equal to the variance of the asymptotic distribution of $\sqrt{n}(T - \psi)$, the two methods of defining asymptotic estimate efficiency are not equivalent. However, they do yield the same efficiency value for a broad class of situations. The investigations of this paper indicate that the second method is preferable from the viewpoint of significance tests and power functions if the asymptotic dis-

tributions are normal. In fact, asymptotic efficiency as defined by the second method satisfies (b) for a wide class of tests for which the pertinent statistics have asymptotic distributions which are normal. Moreover (b) is strongly satisfied in the sense that asymptotically the power functions are not only approximately the same but are identical. These results are contained in Theorem 1.

That the estimate definition for the efficiency of a significance test does not necessarily satisfy (b) is proved by investigation of several asymptotic and non-asymptotic cases where most powerful tests are available. For the asymptotic examples, the two methods of defining asymptotic efficiency yield the same value but the pertinent statistics do not all have asymptotic distributions which are normal. In several of the examples it was found that estimate efficiency makes no allowance for the effect of significance level while the relationship between the power functions of the given test and the corresponding most powerful test changes noticeably with respect to significance level. A case where estimate efficiency implicitly allows for significance level was analyzed. Here, too, estimate efficiences were obtained which do not satisfy (b).

A problem encountered in the investigation of the examples was that of deciding what estimate should be associated with a given test. In some of the cases this was intuitively evident; in the other cases the decision was made on the basis of examples which have appeared in the literature.

3. *Examples.* In this section the value of the estimate efficiency is determined for several significance tests. The power function of the corresponding most powerful test (same significance level) based on a sample size equal to the sample size for the given test times the estimate efficiency of that test is compared with the power function of the given test. For the cases considered, the two power functions are found to be quite different. To show that situations of this type are not limited to non-asymptotic situations, some asymptotic examples are presented.

3.1. *Examples based on t-test.* Let us consider n sample values $x_1, \cdots, x_n$ from a normal population with unknown mean μ and known variance σ^2. The most powerful one-sided test (significance level α) of whether μ is greater than the value zero is

$$\text{(1)} \qquad \textit{Accept } \mu > 0 \textit{ if } \sqrt{n}\,\bar{x}/\sigma > K_\alpha.$$

Here K_α is the value of the standardized normal deviate exceeded with probability α. The most powerful t-test of $\mu > 0$ at significance level α is

$$\text{(2)} \qquad \textit{Accept } \mu > 0 \textit{ if } \bar{x}\sqrt{n(n-1)}/\sqrt{\Sigma(x_i - \bar{x})^2} > t_\alpha,$$

where t_α is the deviate of the t-distribution with $n-1$ degrees of freedom which is exceeded with probability α.

Following the method used in [4], let the statistic associated with test (2) be

$$\bar{x}/\sqrt{\sum(x_i-\bar{x})^2/(n-1)}. \tag{3}$$

The parameter estimated by this statistic is μ/σ. If $n \geq 4$, the variance of (3) is $(n-1)/n(n-3)$ for the case where $\mu = 0$. The minimum variance estimate of μ/σ is $\bar{x}/\sigma$ which has variance $1/n$. Thus the estimate efficiency (based on the method of [4]) of test (2) is $100(n-3)/(n-1)$ per cent.

Now let us compare the power function of test (1) based on $n(n-3)/(n-1)$ sample values with the power function of test (2) based on n sample values. The power function values ϵ for test (1) are determined by the relation

$$K_\epsilon = K_\alpha - \rho\sqrt{(n-3)/(n-1)},$$

where $\rho = \sqrt{n}\,\mu/\sigma$. This comparison is presented in Table 1 for $n = 6$, 10, 14 and $\alpha = .01, .05$. The power function values for test (2) were taken from [5].

TABLE 1

Power function comparison for tests (1) and (2)

n	TEST	SAMPLE SIZE FOR TEST	SIGNIFICANCE LEVEL	VALUES OF POWER FUNCTION					
				$\rho=1$	$\rho=2$	$\rho=3$	$\rho=4$	$\rho=5$	$\rho=6$
6	(1)	3.6	.01	.063	.219	.499	.795	.939	.990
	(2)	6	.01	.059	.204	.453	.715	.892	.971
10	(1)	7.78	.01	.074	.286	.624	.885	.981	.998
	(2)	10	.01	.071	.268	.587	.853	.969	.996
14	(1)	11.85	.01	.080	.314	.668	.912	.989	
	(2)	14	.01	.077	.298	.640	.893	.983	
6	(1)	3.6	.05	.192	.462	.702	.927	.987	
	(2)	6	.05	.219	.531	.822	.960	.995	
10	(1)	7.78	.05	.222	.547	.841	.970	.997	
	(2)	10	.05	.236	.580	.868	.982	.999	
14	(1)	11.85	.05	.234	.578	.868	.978	.998	
	(2)	14	.05	.243	.599	.884	.984	.999	

Examination of Table 1 shows that the estimate efficiency computed for test (2) definitely does not satisfy condition (b). In the cases where $\alpha = .01$, all the power function values computed for test (1) are greater than the corresponding values for test (2); for the cases where $\alpha = .05$ the reverse situation is true. These results bring out the interesting and important fact that any definition for the efficiency of test (2) which satisfies condition (b) necessarily varies with the significance level of the test. Thus any general definition for the efficiency of significance tests which makes no allowance for the significance level of the test can not be considered satisfactory from the viewpoint of condition (b).

3.2. *Sign test examples.* Again let us consider n sample values $x_1, \cdots, x_n$ from a normal population with unknown mean μ and known variance σ^2. The most powerful test of $\mu > 0$ at significance level α is test (1). Let $y_1, \cdots, y_n$ represent the values of $x_1, \cdots, x_n$ arranged in increasing order of magnitude. The one-sided sign test of $\mu > 0$ is

(4) $$\textit{Accept } \mu > 0 \textit{ if } y_i > 0.$$

The significance level of this test has the value

$$(\tfrac{1}{2})^n \sum_{s=0}^{i-1} \frac{n!}{s!(n-s)!}.$$

The statistic associated with test (4) will be y_i. This choice is motivated both on intuitive grounds and by the literature. If the method of [4] were followed and an estimate of μ/σ obtained, the estimate obtained would be of the form $c + y_i/\sigma$, where c is independent of μ; this is equivalent to using y_i. Choice of this statistic implicitly allows for the effect of significance level since the significance level of test (4) changes with the value of i.

The statistic y_i is an estimate of a parameter of the form $\mu + K\sigma$ where K is independent of μ. The minimum variance estimate of $\mu + K\sigma$ is $\bar{x} + K\sigma$, which has variance σ^2/n. Let $v(y_i)\sigma^2$ represent the value of the variance of y_i. Then the estimate efficiency of test (4) is $100/n\,v(y_i)$ per cent. Values of $v(y_i)$ for $n \leq 10$ are given in [6].

Let us compare the power function of test (1) based on $1/v(y_i)$ sample values with the power function of test (4) based on n sample values. For this case the power function values ϵ of test (1) are determined by the relation

$$K_\epsilon = K_\alpha - \delta/\sqrt{v(y_i)},$$

where $\delta = \mu/\sigma$. This comparison is presented in Table 2 for $n = 6$, $i = 1$; $n = 9$, $i = 2$; $n = 10$, $i = 2$. Here the power function values for test (4) were computed from the power function expression

$$\sum_{s=0}^{i-1} \frac{n!}{s!(n-s)!} [1 - N(\delta)]^s [N(\delta)]^{n-s},$$

where

$$N(\delta) = (1/\sqrt{2\pi}) \int_{-\infty}^{\delta} e^{-x^2/2}\, dx.$$

Examination of Table 2 shows that the estimate efficiencies obtained for test (4) do not satisfy condition (b). Thus the estimate method of defining the efficiency of a test does not necessarily satisfy condition (b) even when allowance is made for the effect of significance level. Consequently, on the basis of the examples of Sections 3.1 and 3.2, the estimate method for defining the efficiency of significance tests would seem to be unsatisfactory from the viewpoint of condition (b) for the case of small samples.

TABLE 2

Power function comparison for tests (1) and (4)

n	TEST	SAMPLE SIZE FOR TEST	SIGNIFICANCE LEVEL	VALUES OF POWER FUNCTION				
				$\delta = \frac{1}{2}$	$\delta = 1$	$\delta = 1\frac{1}{2}$	$\delta = 2$	$\delta = 2\frac{1}{2}$
6	(1)	2.40	.0156	.084	.273	.568	.801	.957
	(4), $i = 1$	6	.0156	.109	.354	.661	.871	.964
9	(1)	4.42	.0195	.155	.514	.861	.983	.999
	(4), $i = 2$	9	.0195	.182	.596	.883	.983	.999
10	(1)	4.67	.0107	.111	.444	.826	.978	.999
	(4), $i = 2$	10	.0107	.137	.511	.858	.979	.999

3.3. *Asymptotic examples.* The preceding analysis indicates that the estimate method of defining the efficiency of tests can be very unsuitable for small sample sizes. The purpose of this section is to point out that examples of the types presented in Sections 3.1 and 3.2 are not limited to small sample sizes. The procedure used to demonstrate this result consists in constructing examples based on medium and large sample sizes which can be modified to a form where they are equivalent to the small sample cases already investigated.

Let us consider a sample of size nr from a normal population with unknown mean μ and known variance σ^2. These nr values are obtained as n samples of size r. Form the mean for each of the n samples and denote the resulting means by $x_1, \cdots, x_n$. These n values represent a sample of size n from a normal population with unknown mean μ and known variance σ^2/r. Thus, for any given value of r (n is considered fixed), the examples and analyses of Sections 3.1 and 3.2 applied to $x_1, \cdots, x_n$ hold in full if σ^2 is replaced by σ^2/r. This shows that these small sample examples are also applicable when the sample size is not small. In particular, these results carry over to the asymptotic case (letting $r \to \infty$). For the first method of defining asymptotic estimate efficiency, this follows directly. Since the two definitions of asymptotic estimate efficiency can be proved equivalent for the examples considered, this also holds for the other definition of asymptotic estimate efficiency.

4. *General asymptotic results.* The analysis of Section 3.3 shows that the estimate method of defining the efficiency of a significance test does not necessarily satisfy condition (b). If the pertinent statistics have asymptotic distributions which are normal and the second definition of asymptotic estimate efficiency is used, however, it is possible to obtain an asymptotic estimate efficiency which does satisfy condition (b) for a wide class of situations. Theorem 1 contains a statement and proof of these results.

Theorem 1 is based on three conditions, denoted by (i), (ii), (iii). Although these conditions may appear cumbersome, there are definite reasons for their inclusion. Moreover, these conditions are not very restrictive in the sense that they are satisfied for many situations of practical interest. A short discussion of the reasons for including these conditions will be given prior to the statement and proof of Theorem 1.

In its general form, a significance test is defined by a specified region of the n-dimensional space of sample values. This region may not be easy to define in the form of a function of the sample values and inequalities. Consequently deciding what statistic is to be associated with an arbitrary significance test is a difficult problem. This paper makes no attempt to solve the general problem. Instead consideration is limited to a special class of tests which asymptotically can be expressed in a form where the estimate associated with the test is readily chosen and has convenient properties (asymptotic normality, etc.). Condition (i) limits the types of tests considered and defines the properties of the resulting estimates.

If the properties of tests are to be investigated from the viewpoint of condition (b), it is necessary that the class of tests contain a test which is most powerful for the set of alternative hypotheses considered. Thus the class considered is required to have a most powerful test. Also the pathological situations where the power function of the most powerful test never exceeds the significance level, and where the estimate efficiency is a function of the true value of the parameter tested, are not of much interest but can cause trouble in the analysis. Consequently these cases are eliminated. The stipulation of a most powerful test and the elimination of these troublesome situations are contained in condition (ii).

Finally some requirements concerning the existence and properties of an asymptotically efficient estimate of the parameter estimated by the statistics associated with the tests are included. This estimate is assumed to have convenient properties; one of these properties is that it can be modified to furnish a significance test which is a member of the class considered. These requirements are contained in condition (iii).

Condition (i) defines how estimates can be obtained from tests while condition (iii) defines how the asymptotically most efficient estimate can be used to form a test. Condition (ii) assures the existence of a most powerful test and eliminates certain bothersome situations. Consideration of the properties of the estimate furnished by the most powerful test compared with the properties of the asymptotically most efficient estimate, combined with consideration of properties of the test furnished by the asymptotically most efficient estimate compared with the properties of the most powerful test, yields Theorem 1.

THEOREM 1. *Let us consider a class of significance tests for comparing the point ϕ of a parameter space Ω with a given point ϕ_0 on the basis of a sample of size n (denoted by O_n) from a population whose distribution depends on the parameters with space Ω (and perhaps other parameters). This class consists of all tests which satisfy*

(i) *Asymptotically each test β has significance level α and can be expressed in the form*

$$\text{Accept } \phi \neq \phi_0 \text{ if } \sqrt{n}[T_\beta(O_n;\phi_0) + U_\beta(O_n;\phi_0)] > 0,$$

where the asymptotic distributions of $\sqrt{n}(T_\beta - \psi)$ and $\sqrt{n}(T_\beta + U_\beta - \psi + K_\alpha\sigma_\beta/\sqrt{n})$ are normal with zero mean and variance σ_β^2. Here ψ is a function of ϕ_0 and the parameters of the population which is independent of n and β.

If this class of tests satisfies the additional condition

(ii) *For the given value* ϕ_0 *and a specified set of alternatives* $\omega \varepsilon \Omega$ $(\phi_0 \notin \omega)$ *the class contains a test* γ *which is asymptotically most powerful. For every test* β *of the class,* $\sigma_\beta^2/\sigma_\gamma^2$ *is independent of* ϕ *for* $\phi \varepsilon \omega$. *Also asymptotically the power function of test* γ *is greater than* α *for* $\phi \varepsilon \omega$.

and if there exist statistics $R(O_n; \phi_0)$ *and* $S(O_n; \phi_0)$ *which satisfy*

(iii) *The statistic* R *is an asymptotically efficient estimate of* ψ *for* $\phi \varepsilon \omega$ *in the sense that the asymptotic distribution of* $\sqrt{n}(R - \psi)$ *has zero mean and minimum variance* σ_R^2. *Also the asymptotic distribution of* $\sqrt{n}(R - \psi)$ *is normal while the asymptotic distribution of* $\sqrt{n}(R + S - \psi + K_\alpha \sigma_R/\sqrt{n})$ *is likewise normal with zero mean and variance* σ_R^2.

then an asymptotic efficiency (second method of definition) of $100E\%$ *for the statistic* T_β *implies that asymptotically the most powerful test* γ *based on* nE *sample values has exactly the same power function as test* β *for* $\phi \varepsilon \omega$. *Here* $E = \sigma_\gamma^2/\sigma_\beta^2$ $(\phi \varepsilon \omega)$.

Proof. Since T_γ is an estimate of ψ while R is an asymptotically efficient estimate, $\sigma_\gamma^2 \geq \sigma_R^2$ for $\phi \varepsilon \omega$. For any test β of the class,

$$\Pr[\sqrt{n}(T_\beta + U_\beta) > 0]$$
$$= \Pr[\sqrt{n}(T_\beta + U_\beta - \psi + K_\alpha \sigma_\beta/\sqrt{n})/\sigma_\beta > -\sqrt{n}\,\psi/\sigma_\beta + K_\alpha].$$

It therefore follows from (i) that $\psi = 0$ when $\phi = \phi_0$. Thus the test

$$\textit{Accept } \phi \neq \phi_0 \textit{ if } \sqrt{n}(R + S) > 0.$$

is a member of the class of tests defined in the theorem. Since test γ is asymptotically most powerful, asymptotically

$$\Pr[\sqrt{n}(R + S) > 0]$$
$$= \Pr[\sqrt{n}(R + S - \psi + K_\alpha \sigma_R/\sqrt{n})/\sigma_R > -\sqrt{n}\,\psi/\sigma_R + K_\alpha]$$
$$\leq \Pr[\sqrt{n}(T_\gamma + U_\gamma - \psi + K_\alpha \sigma_\gamma/\sqrt{n})/\sigma_\gamma > -\sqrt{n}\,\psi/\sigma_\gamma + K_\alpha]$$

for $\phi \varepsilon \omega$. As the value of the asymptotic power function of test γ is greater than α for $\phi \varepsilon \omega$, $\psi > 0$ and $\sigma_\gamma^2 \leq \sigma_R^2$ for $\phi \varepsilon \omega$. Thus $\sigma_\gamma^2 = \sigma_R^2$ for $\phi \varepsilon \omega$. Now let us compare the power function of test γ with the

power function of an arbitrary test β of the class for $\phi \varepsilon \omega$. Let test β be based on n sample values while test γ is based on m sample values. The power functions of these tests would be asymptotically equal if a value m could be chosen so that asymptotically

$$\Pr[\sqrt{n}(T_\beta + U_\beta - \psi + K_\alpha\sigma_\beta/\sqrt{n})/\sigma_\beta > -\sqrt{n}\,\psi/\sigma_\beta + K_\alpha]$$
$$= \Pr[\sqrt{m}(T_\gamma + U_\gamma - \psi + K_\alpha\sigma_\gamma/\sqrt{m})/\sigma_\gamma < -\sqrt{m}\,\psi/\sigma_\gamma + K_\alpha].$$

It follows from (i) and (ii) that such a value m can be chosen if $\phi \varepsilon \omega$, and that the power functions will be asymptotically identical for $\phi \varepsilon \omega$ if $m = n\sigma_\gamma^2/\sigma_\beta^2$. Let the estimate efficiency of T_β be denoted by $100E\%$; then $E = \sigma_\gamma^2/\sigma_\beta^2$ and $m = nE$ for $\phi \varepsilon \omega$, thus proving the theorem.

Application to sign test. As an example of the application of Theorem 1, let us consider the well-known sign test based on n sample values $x_1, \cdots, x_n$ from a normal population with unknown mean μ and unknown variance. Here it is desired to compare μ with a given value μ_0.

Let $y_1, \cdots, y_n$ represent the sample values arranged in increasing order of magnitude. The one-sided sign test of $\mu > \mu_0$ is defined by

(5) $$\text{Accept } \mu > \mu_0 \text{ if } y_i - \mu_0 > 0, \quad .$$

where $i = i(\alpha)$ is defined to be the integer which most nearly satisfies the relation $\Pr(y_i > \mu) = \alpha$. By adding and subtracting an appropriate function of the sample values from $y_i - \mu_0$, it is easily seen that test (5) satisfies condition (i). Here $\psi = \mu - \mu_0$.

For the one-sided alternative $\mu > \mu_0$, the asymptotically most powerful test can be expressed in the form

(6) $$\text{Accept } \mu > \mu_0 \text{ if } \bar{x} - \mu_0 - K_\alpha\sqrt{\textstyle\sum(x_i - \bar{x})^2/n(n-1)} > 0.$$

This test satisfies condition (i) and the two tests (5) and (6) jointly satisfy condition (ii). Here $\omega \equiv \mu > \mu_0$.

Finally let $R = \bar{x} - \mu_0$ and $S = \sqrt{\sum(x_i - \bar{x})^2/n(n-1)}$. Then condition (iii) is satisfied. Thus Theorem 1 is applicable to this situation.

For the case considered, the two methods of defining the asymptotic efficiency of an estimate yield the same value. Therefore the asymptotic estimate efficiency of test (5) has the value

$$\lim_{n\to\infty} (1/n + K_\alpha^2/2n^2)/\pi/2n = 2/\pi \doteq 63.7\%.$$

This means that test (6) based on $2n/\pi$ sample values asymptotically has the same power function as test (5) based on n sample values.

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ANTHROPOMETRIC NOMOGRAPH OF ARMY WHITE MEN†

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INTRODUCTION

THE nomograph is a tool which is much more familiar to the physical sciences of chemistry, physics, and engineering than it is to the biological sciences. This is probably because multiple variables are much more commonly used in the experimental phases of those sciences. However, with the extension of physical anthropology into applied fields, it is logical that the development of nomographs, and their use, will materially facilitate the engineering uses of anthropometry. The usual presentation of anthropometry in terms of means, modes, medians, standard deviations, etc., quite often fails to present a total picture of the physical dimensional characteristics of a population. A much more descriptive picture might result if the dimensions, related to at least two independent variables, could be presented in terms of space and direction, rather than by cold, dry numbers.

If descriptive anthropometry, in terms of spatial relationships, were to be prepared, we might find that the common criteria of differences or likenesses of populations might lose some of their historical importance, since two or more populations might, in their total interrelationships, be very closely related, whereas any single dimensional comparison might have led us to the conclusion that the populations were quite different. On the other hand, in those cases where negligible differences appear between individual measurements, the proportional interrelationships may indicate differences of significant value. As a simple example, the means of stature and arm length may very well be identical in two populations. However, the regression slope of arm

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length on stature may be much lower in one population than it is in another. If this is found to be true, we must conclude that the practice of comparing populations solely in terms of their two sets of averages is not a valid process.

In addition to the general theoretical aspects of statistical expressions of anthropometry, there are many different manners in which the use of a nomograph may prove of value. One of these, relative growth, could gain in expression. It is certainly possible that racial differences are, in some respects, a result of environmental effects on the growth processes. Consequently, if means are provided by which several different dimensional aspects of the human body can be portrayed at the same time, the resulting portrayals may indicate whether metric differences are fundamentally genetic, or whether they may more validly be relegated to categories of relative growth, related to specific or general environmental factors. An example of this type of difference has been noted among young white American males with and without military service (Randall, 1949). The mean weight of men with service is higher than is that for men of the same age, without service. Is this difference genetic or environmental? It would appear that a comparison of two nomographs, demonstrating several variables for each of the two groups might answer this. If the two nomographs (i. e. equations of multiple regression) are the same, the differences may be assumed to be environmental; if they differ, the difference is probably genetic. This problem has yet to be answered.

MATERIAL

In order to determine accurately the multiple regression equations which are necessary in the preparation of a nomograph, a population of considerable size is required. In the particular case under discussion a series of 24,500 male, white, Army separatees was used. This series is large enough to permit a nation-wide distribution representative of the population. Further, this sizable population permits an adequate definition, and thus may serve as a base reference for future nomographic comparisons. It must be realized that the definition of the population is always required, because differences or likenesses must ultimately be explained in terms of the definitions.

The series herein described may be defined in terms of United States regional origins, European origins, occupational distributions, marital status, educational background, age, and military status. Other criteria, such as economic level, etc., properly should be included, if obtainable.

The more extensive the description, the greater will be the opportunity to discover reasons for differences, if they occur.

The U. S. regional composition approximates closely that obtained in Selective Service between November 1, 1940 and June 30, 1945.

Region	*Per cent*
New England	6.63
Middle Atlantic	24.34
East North Central	22.09
West North Central	9.75
South Atlantic	11.23
East South Central	7.02
West South Central	8.10
Mountain	3.32
Pacific	7.52
	100.00

(Regional groupings, and others below, are the same as used by the Bureau of the Census.)

National origins were as follows:

	Per cent
Old American *	47.64
British	4.91
Irish	3.93
Latin American	.22
Scandinavian	2.93
Germanic	7.63
Gallic	.81
Balto-Ugric-Slav	5.26
Russian and Soviets	1.79
Southern Slavics	.80
Mediterranean	5.71
Near Eastern	.31
Mixed	18.06
	100.00

* All four grandparents born in the United States.

Occupational groupings reflected most all categories of American living:

	Per cent
Farm	16.23
Labor	5.84
Service	1.11
Protective service	.62
Operatives	15.42
Craftsman	18.94
Salesman	2.75
Clerical	5.51
Property management	1.70
Semi-professional	1.90
Professional	3.36
Student	18.86
Unknown	7.76
	100.00

Of the group, 53.21 per cent were single, 45.40 per cent married, 1.19 per cent divorced, and .1 per cent widowed. Privates and privates first class amounted to 37.42 per cent, non-commissioned officers to 58.30 per cent, and officers to 4.23 per cent. Army Air Force accounted for 15.25 per cent, Service Forces 34.26 per cent, and Ground Forces 50.48 per cent.

Educational background was varied:

	Per cent
Illiterate	.24
Read and write	4.53
Finished grade school	43.77
Finished high school	46.32
Finished special training	1.10
Finished college	2.78
Finished post-graduate	.47
Professional (C.P.A., Ph.D., M.D., D.D., D.D.S., Law)	.79
	100.00

Finally, the age distribution fell between 15 and 65 years. All ages were recorded to last birthday.

Age	*Per cent*	*Age*	*Per cent*
15	.09	29	6.17
16	.32	30	5.95
17	.68	31	3.46
18	1.70	32	1.65
19	12.30	33	' '3
20	27.06	34	1.12
21	5.58	35	.77
22	4.85	36	.74
23	4.16	37	.46
24	3.68	38	.23
25	3.99	39	.11
26	4.09	40	.08
27	4.07	Over 40	.35
28	5.10		
			99.99

Other populations may very well differ from this one in one or more of the above categories. However, some of the categories may or may not affect the physical dimensions. It will require later investigations to establish these effects.

Twenty-five measurements, plus two dimensions collected on a smaller series, are included in the analysis. The dimensions and the methods by which they are obtained are described below.

Stature. Subject stands erect, heels together, looking straight forward, head in the eye-ear plane. Measurement taken to vertex with anthropometer held vertically in rear of subject. Enough pressure applied to compress the hair.

Chest circumference. Erect posture. Start with the tape on the areolae above the nipples. The tape is carried around horizontally. The subject is then allowed to lower his arms and the circumference is recorded, with tape held firmly.

Sleeve length. Subject standing erect, with the right arm raised to a horizontal position, with the upper arm at a 30-45 degree angle forward from the coronal plane, the forearm at right angles with the upper arm, and the hand's volar surface facing downwards. Measured in a horizontal plane from the line of the midsagittal plane posteriorly, over the olecranon process to the most prominent middle point over the styloid process of the ulna, stylion.

Inseam. Subject stands erect with feet slightly apart. The anthropometer is held vertically in front of subject and the arm raised to the highest point in the crotch. The subject then brings his heels together, and the arm of the anthropometer is raised so that it is in contact firmly with the skin.

Waist circumference. Position as for stature. The horizontal circum-

ference taken in a plane midway between the lowest margins of the ribs laterally and the superior margins of the most lateral part of the iliac crests.

Hip circumference. Position as for stature. The horizontal circumference taken over the most lateral part of the greater trochanters of the femurs, trochanterion.

Weight. Taken with physician's scales to the nearest quarter-pound and recorded as .2, .5, and .8 fractions of the pound.

Cervicale height. Subject remains in position for stature. Measurement is taken vertically to cervicale.

Outseam. Subject remains in position for stature. Measurement is taken vertically to right cristale. Enough lateral pressure applied to find cristale. Contact measurement.

Lower leg length. Subject stands erect, heels together. Measurement taken vertically to right tibiale.

Wrist circumference. The minimum circumference in a plane at right angles to the long axis of the forearm taken so that the tape lies superior to the styloid process of the ulna. The tape is tight enough to insure contact.

Total crotch length. The distance from the posterior waist point across the right buttock, through the crotch and up to the anterior waist point. The subject's cooperation is solicited to hold the tape behind so that the observer has the left hand free to carry the tape laterally onto the buttock. The subject's legs are spread adequately to carry the tape through the crotch but the erect posture is assumed before the measurement is read.

Crotch thigh circumference. Erect posture, legs spread slightly to allow passage of the tape between them. The circumference of the thigh taken in a plane at right angles to the long axis of the femur through the gluteal fold.

Bideltoid. Subject stands as for stature. Anthropometer held horizontally, just back of shoulder blades. Measurement taken between the most laterally projecting portions of the deltoids. Contact measurement.

Neck circumference. Subject standing as for stature. With the tape lying at the inferior margin of the thyroid cartilage and the top edge of the tape below the prominence of that cartilage, the minimum circumference of the neck is measured.

Cross back width. Position as for stature. Minimum distance between posterior arm scye points following the curve of the back.

Vertical trunk circumference. Taken with a flexible metallic tape calibrated in feet and tenths of feet. The tape is passed through the crotch, over the maximum prominences of the buttock, and over the shoulder at the mid-clavicular point. If the measurement does not fall exactly on the one-twentieth foot mark, it is read to the next higher twentieth of a foot.

Sitting height. Subject sits on a table with adjustable foot rest. Subject sits erect with thighs just touching the table and knees at right angles. The foot rest is adjusted so that his feet just rest upon it. The knees are together. The measurement is taken vertically from the table to vertex with anthropometer in rear of subject. Enough pressure is applied to compress the hair.

Trunk height. Subject sits as for sitting height. Measurement taken vertically from the table to sternale.

Patella height. Subject sits as for sitting height. Anthropometer held vertically in front of and slightly lateral to the foot. Measurement taken from the foot rest to a point on the superior surface of the knee approximately one inch posterior to the anterior surface of the patella. Contact.

Buttock-knee. Subject sits as for sitting height. With anthropometer held parallel to the line of contact of the legs, the measurement is taken between the most posterior point on the buttock, below the hips, and the most anterior point on the patella. Contact.

Shoulder-elbow. Subject sits as for sitting height. With his right upper arm held against the side, and the forearm held at right angles to it. With anthropometer held parallel to upper arm, measurement is taken from acromiale to inferior surface of the olecranon process with firm contact.

Forearm-hand length. Subject sits as for shoulder-elbow with fingers extended. Anthropometer held parallel to the axis of the forea.m, measure from the posterior point on the olecranon process to dactylion. Firm contact.

Hip breadth. Subject sits as for sitting height. With anthropometer held horizontally in rear of subject and arms extending downward at a forty-five degree angle, measure the maximum transverse diameter of the hips below the iliac crests, with contact.

Elbow breadth. Subject sits as for sitting height. With upper arms at the side and forearms at right angles to them. With anthropometer horizontal in rear of subject, measure the diameter across the most lateral points on the lateral epicondyles of the humeri. Medial condyles are in contact with trunk. Contact.

Shoulder circumference. The measurement is taken as a circumference about the shoulders at the level of the greatest lateral projection of the deltoid muscles. The tape is passed about the shoulders parallel to the floor.

Inside arm. The arm is raised to a forty-five degree angle. The tongue depressor is placed under the upper arm in contact with the axilla, parallel to the floor. The measurement is taken from the superior border of the tongue depressor to the distal end of the radius, with the arm extended. The position of the subject is the same as in measurement for arm length.

TABLE 1. *Dimensional relations to stature and chest*
(All dimensions are in inches)

PREPARATION OF THE NOMOGRAPH

The first step in the preparation of the nomograph is the selection of the two independent variables. Fortunately, in this case, the matter is simplified by the fact that the engineering application and the biological usage involve the same two, stature and chest circumference. Stature is all-inclusive of length, and chest circumference tends to include girth as affected both by skeleton and soft tissues.

The second step is the preparation of a series of distributions of dimensions for each of several incremental categories of stature and chest circumference. These values are given in Table 1. Step two is

TABLE 1. *Dimensional relations to stature and chest*
(All dimensions are in inches)

STATURE	CHEST 31.1 – 33.0	33.1 – 35.0	35.1 – 37.0	37.1 – 39.0	39.1 – 41.0	41.1 – 43.0
73.1 – 75.0	MEAN CHEST 32.21 MEAN STATURE 73.56	MEAN CHEST 34.02 MEAN STATURE 73.56	MEAN CHEST 35.82 MEAN STATURE 73.56	MEAN CHEST 37.69 MEAN STATURE 73.56	MEAN CHEST 39.57 MEAN STATURE 73.56	MEAN CHEST 41.40 MEAN STATURE 73.56
71.1 – 73.0	MEAN CHEST 32.21 MEAN STATURE 71.70	MEAN CHEST 34.02 MEAN STATURE 71.70	MEAN CHEST 35.82 MEAN STATURE 71.70	MEAN CHEST 37.69 MEAN STATURE 71.70	MEAN CHEST 39.57 MEAN STATURE 71.70	MEAN CHEST 41.40 MEAN STATURE 71.70
69.1 – 71.0	MEAN CHEST 32.21 MEAN STATURE 69.82	MEAN CHEST 34.02 MEAN STATURE 69.82	MEAN CHEST 35.82 MEAN STATURE 69.82	MEAN CHEST 37.69 MEAN STATURE 69.82	MEAN CHEST 39.57 MEAN STATURE 69.82	MEAN CHEST 41.40 MEAN STATURE 69.82
67.1 – 69.0	MEAN CHEST 32.21 MEAN STATURE 67.95	MEAN CHEST 34.02 MEAN STATURE 67.95	MEAN CHEST 35.82 MEAN STATURE 67.95	MEAN CHEST 37.69 MEAN STATURE 67.95	MEAN CHEST 39.57 MEAN STATURE 67.95	MEAN CHEST 41.40 MEAN STATURE 67.95
65.1 – 67.0	MEAN CHEST 32.21 MEAN STATURE 66.08	MEAN CHEST 34.02 MEAN STATURE 66.08	MEAN CHEST 35.82 MEAN STATURE 66.08	MEAN CHEST 37.69 MEAN STATURE 66.08	MEAN CHEST 39.57 MEAN STATURE 66.08	MEAN CHEST 41.40 MEAN STATURE 66.08
63.1 – 65.0	MEAN CHEST 32.21 MEAN STATURE 64.21	MEAN CHEST 34.02 MEAN STATURE 64.21	MEAN CHEST 35.82 MEAN STATURE 64.21	MEAN CHEST 37.69 MEAN STATURE 64.21	MEAN CHEST 39.57 MEAN STATURE 64.21	MEAN CHEST 41.40 MEAN STATURE 64.21

TABLE 1. *Dimensional relations to stature and chest (continued)*

CHEST

STATURE

		31.1 – 33.0			33.1 – 35.0			35.1 – 37.0			37.1 – 39.0			39.1 – 41.0			41.1 – 43.0		
73.1 – 75.0	1 SLEEVE LENGTH				MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±
	2 INSEAM				1 33.45	34.08	1.61	1 33.85	33.96	1.28	1 34.20	34.12	1.28	1 34.45	34.03	1.51	1 34.28	35.00	1.44
	3 WAIST CIRCUMFERENCE				2 35.65	35.67	1.28	2 35.78	36.22	1.22	2 35.65	35.97	1.04	2 35.59	35.85	1.19	2 35.43	35.09	.94
	4 HIP CIRCUMFERENCE				3 29.15	28.71	1.77	3 30.11	30.16	1.50	3 31.57	31.14	1.78	3 33.91	33.48	2.56	3 34.96	35.19	2.78
	5 WEIGHT				4 36.11	35.83	1.23	4 37.11	37.22	1.37	4 38.38	38.31	1.56	4 39.58	39.76	1.60	4 40.72	39.71	1.63
	6 CERVICALE HEIGHT				5 151.49	151.43	14.38	5 162.81	163.32	10.40	5 175.96	175.78	11.91	5 192.78	188.73	17.97	5 205.63	200.74	14.13
	7 OUTSEAM				6 63.11	63.11	.87	6 63.38	63.28	.84	6 63.45	63.26	.85	6 63.26	64.00	1.55	6 63.24	63.97	.92
					7 44.54	44.65	1.62	7 44.96	45.38	1.36	7 45.05	45.35	1.24	7 44.98	45.62	1.46	7 45.22	44.96	1.15
71.1 – 73.0		MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±
	1	32.56	32.92	1.18	1 32.88	32.80	1.33	1 33.18	33.14	1.29	1 33.44	33.55	1.33	1 33.67	33.66	1.41	1 33.73	33.81	1.35
	2	34.97	35.57	1.25	2 34.84	34.89	1.04	2 34.78	34.78	1.05	2 34.69	34.76	1.09	2 34.51	34.57	1.07	2 34.46	34.63	1.30
	3	27.63	27.07	1.26	3 29.70	29.57	1.52	3 30.16	29.90	1.66	3 31.67	31.42	1.90	3 33.62	33.42	2.22	3 36.00	35.54	2.60
	4	34.78	34.67	1.16	4 35.81	35.77	1.33	4 36.87	36.84	1.47	4 38.06	38.13	1.51	4 39.48	39.56	1.60	4 40.96	40.39	1.66
	5	137.17	134.86	9.49	5 147.78	146.70	9.67	5 159.62	158.24	11.11	5 171.63	172.50	11.99	5 186.54	185.40	14.42	5 202.91	197.63	14.11
	6	61.61	61.55	.82	6 61.66	61.57	.87	6 61.62	61.60	.75	6 61.74	61.72	.80	6 61.81	61.90	.92	6 61.81	61.73	.81
	7	43.37	44.37	1.56	7 43.75	43.74	1.09	7 43.78	43.87	1.12	7 43.81	44.00	1.10	7 43.75	43.86	1.13	7 43.80	43.86	1.18
69.1 – 71.0		MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±
	1	31.95	32.10	1.28	1 32.15	32.22	1.29	1 32.40	32.45	1.25	1 32.68	32.67	1.34	1 32.88	32.80	1.39	1 33.06	33.02	1.29
	2	33.92	33.86	.95	2 33.75	33.69	1.00	2 33.98	33.51	.98	2 33.58	33.60	.96	2 33.44	33.56	.99	2 33.15	33.04	1.08
	3	27.79	26.91	1.87	3 28.70	28.51	1.49	3 30.13	29.87	1.71	3 31.72	31.36	1.97	3 33.65	33.37	2.49	3 36.19	35.94	2.38
	4	34.48	34.57	1.42	4 35.40	35.41	1.51	4 36.55	36.55	1.42	4 37.78	37.87	1.54	4 39.20	39.16	1.64	4 40.98	40.36	1.68
	5	134.16	132.87	9.76	5 145.10	142.80	9.77	5 156.36	154.63	10.65	5 166.69	166.30	11.69	5 181.97	181.34	14.45	5 199.67	198.19	12.94
	6	59.87	59.65	.78	6 59.91	59.88	.89	6 59.93	60.00	.90	6 60.03	60.04	.94	6 60.14	60.13	.81	6 60.31	60.07	.81
	7	42.37	42.43	1.06	7 42.44	42.48	1.02	7 42.42	42.41	1.00	7 42.51	42.65	1.02	7 42.59	42.40	1.02	7 42.55	42.62	1.10
67.1 – 69.0		MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±
	1	31.28	31.25	1.07	1 31.45	31.38	1.34	1 31.71	31.65	1.35	1 31.95	32.05	1.33	1 32.06	32.07	1.34	1 32.15	32.42	1.22
	2	32.75	32.69	.90	2 32.67	32.63	.98	2 32.95	32.60	1.01	2 32.44	32.42	1.03	2 32.27	32.35	1.01	2 32.06	31.85	1.00
	3	27.57	26.92	1.73	3 28.83	28.53	1.63	3 30.19	29.78	1.74	3 31.90	31.60	2.00	3 33.95	33.49	2.37	3 35.72	35.58	2.22
	4	34.11	34.01	1.33	4 35.19	35.24	1.40	4 36.27	36.38	1.45	4 37.63	37.68	1.53	4 39.03	39.04	1.71	4 40.39	39.98	1.61
	5	129.83	126.23	10.11	5 139.55	137.87	9.52	5 150.61	151.50	10.04	5 163.32	162.76	11.33	5 176.93	177.36	13.26	5 190.86	190.29	12.68
	6	58.13	58.17	.81	6 58.22	58.13	.86	6 58.26	58.25	.87	6 58.40	58.42	.89	6 58.43	58.41	.78	6 58.54	58.51	.89
	7	41.18	41.33	.92	7 41.19	41.27	.95	7 41.21	41.26	.92	7 41.21	41.29	.98	7 41.26	41.30	.99	7 41.22	41.41	.96
65.1 – 67.0		MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±
	1	30.29	30.31	1.24	1 30.62	30.52	1.28	1 30.91	30.86	1.29	1 31.25	31.30	1.31	1 31.46	31.39	1.29	1 31.39	30.89	1.48
	2	31.59	31.68	.96	2 31.55	31.52	.99	2 31.45	31.36	1.03	2 31.35	31.28	.97	2 31.16	30.99	1.02	2 31.00	31.07	.96
	3	27.45	27.39	1.19	3 28.63	28.36	1.47	3 30.15	29.75	1.69	3 31.83	31.52	2.05	3 33.83	33.15	2.51	3 36.42	35.83	2.68
	4	33.90	33.98	1.20	4 34.94	34.91	1.36	4 36.05	35.94	1.40	4 37.17	37.32	1.68	4 38.74	38.70	1.74	4 40.43	39.98	2.01
	5	125.64	125.01	8.06	5 135.10	134.68	9.28	5 146.31	145.25	10.07	5 157.83	157.05	11.43	5 171.01	171.25	13.96	5 188.68	182.65	13.85
	6	56.43	56.54	.76	6 56.54	56.57	.83	6 56.61	56.61	.85	6 56.69	56.72	.76	6 56.78	56.67	.78	6 56.81	56.87	.88
	7	39.80	39.78	.94	7 39.91	39.82	.91	7 39.89	39.93	.99	7 39.95	39.86	1.00	7 40.03	40.12	.98	7 39.77	39.60	.86
63.1 – 65.0		MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±			
	1	29.74	29.79	1.30	1 29.77	29.68	1.39	1 30.22	30.08	1.30	1 30.28	30.34	1.44	1 30.43	30.08	1.51			
	2	30.56	30.65	.94	2 30.49	30.44	1.02	2 30.36	30.30	.97	2 30.32	30.40	.99	2 30.08	29.95	1.10	ALL DIMENSIONS		
	3	27.42	27.22	1.27	3 28.69	28.38	1.63	3 30.17	29.87	1.75	3 31.84	31.47	2.23	3 34.78	34.74	2.67			
	4	33.62	33.48	1.28	4 34.57	34.75	1.41	4 35.77	35.69	1.39	4 36.85	37.06	1.72	4 38.52	38.71	1.62	ARE IN INCHES		
	5	121.64	122.72	7.89	5 130.71	130.47	8.93	5 141.95	142.23	9.63	5 152.97	154.97	11.36	5 168.77	161.96	13.06			
	6	54.81	54.70	.81	6 54.84	54.95	.84	6 54.92	54.88	.80	6 54.96	55.03	.73	6 55.21	55.35	.81			
	7	38.65	38.56	.91	7 38.61	38.72	1.03	7 38.65	38.64	1.07	7 38.58	38.71	.98	7 38.64	38.32	.86			

TABLE 1. *Dimensional relations to stature and chest (continued)*

TABLE 1. *Dimensional relations to stature and chest (continued)*

CHEST

STATURE		31.1 – 33.0			33.1 – 35.0			35.1 – 37.0			37.1 – 39.0			39.1 – 41.0			41.1 – 43.0		
			MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±
73.1 – 75.0	8 LOWER LEG LENGTH					8 19.22	19.43	1.07	8 19.34	19.29	.83	8 19.39	19.45	.88	8 19.48	19.68	.96	8 19.68	19.09	.88
	9 WRIST CIRC.					9 6.58	6.68	.32	9 6.82	6.78	.29	9 6.93	7.05	.33	9 7.12	7.08	.33	9 7.22	7.28	.09
	10 TOTAL CROTCH LENGTH					10 28.35	28.52	1.65	10 28.90	29.02	1.90	10 29.54	29.75	1.86	10 30.53	30.04	2.35	10 31.74	31.01	2.45
	11 CROTCH THIGH CIRC.					11 20.18	20.24	1.00	11 20.83	20.94	.82	11 21.91	21.83	1.03	11 23.39	23.41	1.21	11 23.94	23.78	.76
	12 BIDELTOID					12 17.67	17.47	.78	12 18.06	18.16	.67	12 18.64	18.70	.65	12 19.27	19.21	.75	12 19.80	19.94	.77
	13 NECK CIRC.					13 14.11	14.00	.55	13 14.51	14.39	.51	13 14.80	14.83	.58	13 15.16	15.25	.54	13 15.67	15.32	.79
	14 CROSS BACK WIDTH					14 14.44	14.71	1.11	14 14.80	14.81	1.02	14 15.35	15.43	1.04	14 15.74	15.91	.94	14 16.15	15.77	1.12
71.1 – 73.0		MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±
	8	18.74	19.07	.94	8 18.84	18.67	.88	8 18.79	18.66	.82	8 18.93	18.74	.87	8 18.99	18.80	.94	8 18.87	18.88	.84	
	9	6.41	6.18	.29	9 6.52	6.55	.34	9 6.75	6.78	.33	9 6.92	6.96	.33	9 7.09	7.08	.35	9 7.17	7.18	.36	
	10	27.29	28.40	1.65	10 28.07	28.10	1.88	10 28.81	28.59	1.80	10 29.40	29.39	2.00	10 30.33	30.37	2.19	10 31.40	31.48	2.21	
	11	18.62	19.21	.68	11 20.22	20.02	1.08	11 21.13	21.00	1.18	11 22.04	21.94	1.16	11 23.26	23.25	1.40	11 24.58	25.13	1.18	
	12	17.07	16.99	.70	12 17.46	17.52	.75	12 18.01	18.00	.62	12 18.51	18.58	.67	12 19.09	19.30	.71	12 19.59	19.65	.73	
	13	13.63	13.37	.59	13 14.03	13.90	.57	13 14.44	14.41	.56	13 14.81	14.75	.59	13 15.21	15.22	.61	13 15.50	15.41	.58	
	14	13.85	13.64	1.17	14 14.30	14.22	.98	14 14.83	14.86	1.04	14 15.32	15.32	1.04	14 15.76	15.70	1.13	14 16.19	16.13	1.16	
69.1 – 71.0		MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±
	8	18.20	18.13	.79	8 18.25	18.11	.80	8 18.23	18.11	.84	8 18.30	18.24	.88	8 18.37	18.31	.83	8 18.37	18.27	.90	
	9	6.33	6.29	.32	9 6.49	6.55	.31	9 6.69	6.74	.33	9 6.89	6.93	.34	9 7.03	7.07	.36	9 7.23	7.26	.33	
	10	27.29	27.61	1.80	10 27.82	27.89	1.60	10 28.44	28.36	1.87	10 29.05	29.11	1.98	10 30.14	29.95	2.21	10 31.26	31.07	2.03	
	11	19.25	19.02	1.10	11 20.03	19.93	1.09	11 21.00	20.99	1.20	11 22.08	22.04	1.20	11 23.30	23.41	1.36	11 24.46	24.16	1.21	
	12	16.92	16.78	.69	12 17.37	17.39	.63	12 17.86	17.88	.63	12 18.44	18.51	.64	12 19.05	19.03	.72	12 19.72	19.62	.71	
	13	13.69	13.56	.61	13 14.03	13.95	.54	13 14.41	14.38	.56	13 14.77	14.76	.58	13 15.12	15.11	.62	13 15.55	15.45	.62	
	14	13.91	13.95	1.08	14 14.32	14.38	1.05	14 14.77	14.70	1.03	14 15.26	15.31	1.00	14 15.65	15.66	1.08	14 16.21	16.34	1.07	
67.1 – 69.0		MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±
	8	17.59	17.56	.73	8 17.68	17.56	.78	8 17.70	17.58	.78	8 17.75	17.63	.86	8 17.68	17.67	.79	8 17.78	17.76	.69	
	9	6.29	6.30	.33	9 6.48	6.54	.33	9 6.67	6.72	.33	9 6.85	6.87	.34	9 6.98	7.04	.33	9 7.17	7.27	.34	
	10	26.93	26.92	1.80	10 27.52	27.39	1.85	10 28.18	28.08	1.87	10 29.03	28.87	1.97	10 30.02	29.89	1.98	10 30.92	30.93	2.16	
	11	19.17	19.00	.95	11 20.22	20.17	1.15	11 21.13	21.29	1.13	11 22.12	22.35	1.21	11 23.24	23.03	1.30	11 24.41	24.54	1.26	
	12	16.82	16.71	.71	12 17.30	17.31	.63	12 17.81	17.87	.61	12 18.36	18.37	.65	12 18.97	19.07	.74	12 19.59	19.57	.76	
	13	13.66	13.61	.53	13 14.02	13.96	.53	13 14.39	14.35	.56	13 14.77	14.75	.58	13 15.09	15.06	.64	13 15.38	15.40	.56	
	14	13.83	13.83	1.09	14 14.30	14.28	1.00	14 14.71	14.68	1.04	14 15.19	15.16	1.03	14 15.68	15.82	1.02	14 16.09	16.24	1.10	
65.1 – 67.0		MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±
	8	17.06	16.92	.74	8 17.13	17.02	.61	8 17.22	17.08	.83	8 17.20	17.15	.75	8 17.29	17.02	.78	8 17.17	16.93	.94	
	9	6.26	6.29	.32	9 6.46	6.51	.34	9 6.66	6.69	.34	9 6.80	6.82	.34	9 6.94	6.94	.34	9 7.00	7.09	.31	
	10	26.73	26.43	1.70	10 27.15	27.07	1.80	10 27.99	27.80	1.93	10 28.57	28.53	1.95	10 29.75	29.87	2.00	10 31.34	31.97	2.93	
	11	19.38	19.37	.98	11 20.17	20.20	1.14	11 21.18	21.09	1.16	11 22.12	22.22	1.14	11 23.02	22.91	1.33	11 23.98	23.72	1.09	
	12	16.69	16.67	.60	12 17.20	17.13	.63	12 17.71	17.79	.61	12 18.26	18.29	.67	12 18.85	18.89	.76	12 19.35	19.56	.90	
	13	13.61	13.59	.52	13 14.02	13.92	.51	13 14.36	14.32	.58	13 14.73	14.71	.57	13 15.10	15.07	.65	13 15.43	15.52	.72	
	14	13.83	13.93	.98	14 14.24	14.24	.99	14 14.67	14.69	1.02	14 15.16	15.16	.99	14 15.46	15.25	1.01	14 15.98	15.98	1.03	
63.1 – 65.0		MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±				
	8	16.48	16.51	.81	8 16.58	16.35	.85	8 16.65	16.65	.89	8 16.77	16.72	.80	8 16.53	16.80	.93				
	9	6.19	6.11	.32	9 6.41	6.56	.30	9 6.58	6.62	.33	9 6.77	6.84	.34	9 6.89	6.96	.32				
	10	26.35	26.64	1.66	10 26.90	26.79	1.86	10 27.67	27.25	1.79	10 28.58	28.35	1.75	10 29.78	30.21	2.32				
	11	19.20	18.91	1.09	11 20.15	20.09	1.04	11 21.11	21.14	1.13	11 22.10	22.32	1.14	11 23.24	22.55	1.46				
	12	16.56	16.59	.42	12 17.05	17.07	.61	12 17.38	17.71	.71	12 18.18	18.36	.66	12 18.87	19.02	.80				
	13	13.62	13.65	.56	13 13.97	13.93	.56	13 14.37	14.38	.56	13 14.74	14.72	.64	13 15.12	15.08	.74				
	14	13.67	13.81	.94	14 14.16	14.19	1.00	14 14.65	14.71	1.00	14 15.07	15.11	.98	14 15.59	15.59	.79				

ALL DIMENSIONS ARE IN INCHES

TABLE 1. *Dimensional relations to stature and chest (continued)*

CHEST

STATURE		311 – 330			331 – 350			351 – 370			371 – 390			391 – 410			411 – 430		
			MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±
731 – 750	15 VERTICAL TRUNK CIRC.				15 63.60	63.80	2.30	15 64.08	64.08	1.94	15 65.04	64.68	1.96	15 66.16	65.90	2.22	15 66.24	66.60	2.81
	16 SITTING HEIGHT				16 37.48	37.98	1.18	16 37.67	37.85	.94	16 37.72	38.61	.99	16 37.90	37.60	.92	16 38.00	37.68	.94
	17 TRUNK HEIGHT				17 24.20	24.83	1.07	17 24.39	24.69	.73	17 24.43	24.56	.75	17 24.79	24.90	.99	17 24.71	25.19	.80
	18 PATELLA HEIGHT				18 23.01	23.19	.86	18 23.30	23.42	.67	18 23.42	23.50	.75	18 23.47	23.63	.72	18 23.60	23.33	.66
	19 BUTTOCK KNEE				19 24.57	24.74	1.01	19 24.97	25.15	.68	19 25.14	25.20	.73	19 25.42	25.20	.77	19 25.47	25.44	.76
	20 SHOULDER ELBOW				20 14.96	14.97	.74	20 15.32	15.34	.55	20 15.34	15.39	.59	20 15.40	15.07	.61	20 15.31	15.15	.37
	21 FOREARM HAND LENGTH				21 19.74	19.95	.60	21 20.00	19.94	.58	21 20.10	20.04	.56	21 20.07	20.03	.58	21 20.09	19.97	.50
711 – 730		MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±
	15	61.68	61.68	2.01	15 62.76	62.76	1.81	15 63.48	63.12	1.98	15 64.32	63.96	1.87	15 65.18	64.90	1.97	15 66.12	66.48	2.26
	16	37.10	37.09	.97	16 36.97	37.09	.98	16 37.04	37.10	.95	16 37.06	37.12	.97	16 37.12	37.17	.93	16 37.05	37.03	.95
	17	23.49	23.96	1.23	17 23.80	23.86	.93	17 23.88	23.91	.98	17 23.86	24.06	.94	17 24.10	24.17	.88	17 24.06	24.32	.90
	18	22.26	22.34	.58	18 22.56	22.59	.66	18 22.63	22.63	.73	18 22.71	22.76	.71	18 22.84	22.86	.69	18 22.97	22.86	.69
	19	24.05	24.61	.79	19 24.25	24.17	.73	19 24.41	24.34	.73	19 24.56	24.67	.74	19 24.75	24.78	.72	19 25.03	25.15	.74
	20	14.79	14.86	.53	20 14.84	14.77	.56	20 14.93	14.95	.57	20 14.96	15.07	.56	20 14.97	15.02	.58	20 15.06	15.25	.66
	21	19.29	19.55	.78	21 19.44	19.36	.53	21 19.54	19.60	.57	21 19.59	19.68	.59	21 19.70	19.76	.56	21 19.79	19.69	.59
691 – 710		MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±
	15	61.08	60.72	1.84	15 61.68	61.68	1.87	15 62.57	62.35	1.82	15 63.36	63.00	1.91	15 64.52	64.20	2.02	15 65.76	65.76	2.12
	16	36.08	36.08	.90	16 36.24	36.35	.93	16 36.34	36.43	.90	16 36.35	36.51	.88	16 36.34	36.30	.91	16 36.46	36.59	.93
	17	23.26	23.20	.97	17 23.25	23.37	.91	17 23.40	23.52	.94	17 23.46	23.47	.95	17 23.48	23.51	.90	17 23.68	23.46	.93
	18	21.84	21.91	.58	18 21.93	22.01	.64	18 22.02	22.01	.64	18 22.15	22.22	.65	18 22.24	22.30	.65	18 22.38	22.37	.65
	19	23.47	23.52	.72	19 23.62	23.56	.70	19 23.75	23.87	.72	19 23.96	23.89	.71	19 24.21	24.14	.68	19 24.42	25.26	.70
	20	14.40	14.56	.59	20 14.42	14.43	.56	20 14.52	14.56	.56	20 14.59	14.66	.61	20 14.65	14.54	.55	20 14.67	14.76	.66
	21	18.85	18.86	.52	21 18.95	18.98	.56	21 19.02	19.09	.59	21 19.14	19.15	.56	21 19.16	19.22	.60	21 19.32	19.17	.63
671 – 690		MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±
	15	60.24	59.88	1.96	15 60.72	60.72	1.88	15 61.63	61.52	1.93	15 62.50	62.42	1.96	15 63.72	63.72	2.30	15 64.56	64.20	2.15
	16	35.49	35.50	.87	16 35.51	35.50	.92	16 35.58	35.62	.91	16 35.68	35.73	.90	16 35.69	35.84	.91	16 35.75	35.76	.88
	17	22.88	22.70	.87	17 22.79	22.92	.94	17 22.86	22.85	.90	17 22.98	23.00	.93	17 23.10	23.20	.90	17 23.32	23.43	.94
	18	21.28	21.22	.62	18 21.30	21.35	.62	18 21.44	21.46	.63	18 21.51	21.54	.66	18 21.62	21.70	.64	18 21.69	21.74	.67
	19	22.84	22.68	.71	19 23.05	23.07	.68	19 23.19	23.16	.67	19 23.36	23.39	.70	19 23.64	23.70	.69	19 23.77	23.74	.62
	20	14.08	14.00	.52	20 14.11	14.08	.61	20 14.17	14.20	.60	20 14.20	14.18	.58	20 14.16	14.16	.57	20 14.32	14.30	.53
	21	18.45	18.52	.53	21 18.50	18.56	.54	21 18.60	18.61	.54	21 18.65	18.66	.55	21 18.67	18.60	.62	21 18.74	18.80	.54
651 – 670		MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±
	15	59.16	59.16	2.11	15 59.68	59.52	1.99	15 60.74	60.89	2.17	15 61.60	61.42	1.76	15 62.64	62.64	2.00	15 63.96	63.60	2.17
	16	34.76	34.77	.90	16 34.75	34.85	.88	16 34.87	34.83	.93	16 34.91	34.88	.83	16 34.90	34.98	.81	16 34.92	35.02	.92
	17	22.17	22.18	.69	17 22.28	22.43	.95	17 22.34	22.46	.92	17 22.43	22.48	.89	17 22.66	22.58	.90	17 22.72	22.71	.97
	18	20.58	20.61	.60	18 20.75	20.78	.65	18 20.73	21.06	.66	18 20.91	20.90	.63	18 21.04	21.04	.65	18 21.13	21.11	.65
	19	22.22	22.29	.70	19 22.44	22.41	.64	19 22.58	22.65	.65	19 22.78	22.80	.68	19 23.00	22.98	.65	19 23.32	23.22	.66
	20	13.65	13.63	.51	20 13.76	13.61	.60	20 13.80	13.81	.54	20 13.85	13.84	.55	20 13.88	13.88	.53	20 13.79	13.70	.62
	21	17.98	17.94	.54	21 18.06	18.12	.55	21 18.17	18.18	.56	21 18.21	18.22	.54	21 18.22	18.18	.53	21 18.10	17.91	.55
631 – 650		MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±			
	15	58.32	57.24	2.58	15 59.30	58.37	2.21	15 59.69	59.51	2.14	15 60.44	59.47	2.16	15 61.80	61.44	2.69			
	16	33.84	33.63	.84	16 34.08	33.98	.97	16 34.15	34.07	.98	16 34.10	34.16	.86	16 34.37	34.12	.93	ALL DIMENSIONS		
	17	21.64	21.78	.86	17 21.72	21.78	.95	17 21.85	21.79	.90	17 21.84	21.78	.86	17 22.23	22.42	.84	ARE IN INCHES		
	18	20.08	19.98	.73	18 20.16	20.94	.75	18 20.23	20.21	.67	18 20.34	20.21	.73	18 20.39	20.60	.63			
	19	21.75	21.76	.65	19 21.76	21.76	.74	19 21.98	21.88	.66	19 22.18	22.17	.62	19 22.07	23.08	.67			
	20	13.41	13.48	.52	20 13.36	13.41	.59	20 13.42	13.36	.57	20 13.47	13.40	.55	20 13.44	13.44	.50			
	21	17.56	17.49	.56	21 17.58	17.54	.56	21 17.67	17.73	.55	21 17.69	17.56	.60	21 17.70	17.61	.46			

TABLE 1. *Dimensional relations to stature and chest (continued)*

21	17.56	17.49	.56	21	17.55	17.54	.56	21	17.67	17.73	.55	21	17.69	17.55	.60	21	17.70	17.61	.46			

TABLE 1. ***Dimensional relations to stature and chest*** **(*continued*)**

CHEST

STATURE	31.1 – 33.0			33.1 – 35.0			35.1 – 37.0			37.1 – 39.0			39.1 – 41.0			41.1 – 43.0		
73.1 – 75.0	22 HIP BREADTH 23 ELBOW BREADTH 24 SHOULDER CIRCUMFERENCE 25 INSIDE ARM LENGTH %			MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±
				22 13.97	13.96	.61	22 14.14	14.35	.56	22 14.60	14.50	.62	22 15.16	15.25	.73	22 15.55	15.41	.73
				23 16.56	15.79	1.08	23 17.17	16.89	1.04	23 16.09	17.77	1.23	23 19.06	19.07	1.37	23 20.10	20.04	1.34
							24 44.03	45.11	1.46									
							25 19.56	19.24	.76									
				384			878			980			441			101		
71.1 – 73.0		MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±
	22	13.50	13.94	.56	22 13.78	13.71	.57	22 14.14	13.89	.72	22 14.44	14.37	.77	22 14.89	14.85	.68	22 15.64	15.52	.87
	23	15.70	16.11	.85	23 16.50	16.16	1.08	23 17.34	16.98	1.19	23 16.01	17.80	1.20	23 18.98	18.77	1.22	23 20.14	19.30	1.49
					24 42.42	42.28	1.34	24 43.79	44.32	1.50	24 44.84	45.26	1.78						
					25 18.99	19.04	.78	25 18.98	19.10	.77	25 18.88	19.00	.71						
		245			1.747			4.278			3.910			1.902			.469		
69.1 – 71.0		MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±
	22	13.28	13.28	.55	22 13.58	13.52	.60	22 13.90	13.86	.64	22 14.36	14.24	.72	22 14.80	14.68	.78	22 15.32	15.12	.79
	23	15.88	15.79	1.06	23 16.92	16.22	1.09	23 17.28	17.02	1.15	23 18.12	17.88	1.19	23 19.12	18.56	1.34	23 20.17	20.20	1.37
	24	40.90	41.15	1.12	24 42.49	42.87	1.29	24 43.62	44.44	1.52	24 44.78	44.64	.98	24 46.32	47.13	1.42			
	25	18.67	18.68	.64	25 18.58	18.66	.78	25 18.32	18.31	.70	25 18.15	18.52	.88	25 18.14	18.41	.70			
		.922			5.061			8.951			6.992			2.865			.874		
67.1 – 69.0		MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±
	22	13.18	13.08	.59	22 13.42	13.34	.64	22 13.75	13.70	.59	22 14.20	14.07	.73	22 14.65	14.62	.71	22 15.17	14.81	.75
	23	15.85	15.37	1.21	23 16.64	16.43	1.14	23 17.34	17.13	1.09	23 18.15	17.94	1.19	23 19.20	18.78	1.26	23 20.03	19.58	1.25
	24	40.78	40.98	.91	24 42.04	42.18	1.40	24 43.42	43.70	1.34	24 44.74	44.18	1.30						
	25	17.82	17.64	.69	25 17.82	17.94	.72	25 17.74	17.91	.66	25 17.72	17.54	.78						
		1.563			7.188			10.910			7.049			2.510			.592		
65.1 – 67.0		MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±
	22	12.97	12.85	.57	22 13.29	13.09	.72	22 13.62	13.51	.64	22 14.03	13.84	.72	22 14.53	14.40	.80	22 15.12	14.85	.77
	23	15.98	15.56	1.20	23 16.36	16.74	1.14	23 17.37	17.13	1.12	23 18.21	17.94	1.22	23 19.06	18.71	1.20	23 19.74	20.20	1.19
	24	40.39	40.87	1.20	24 42.06	42.26	1.43	24 42.72	42.72	.50	24 44.93	45.66	1.07						
	25	17.22	16.94	.57	25 17.20	17.30	.85	25 17.10	17.12	.83	25 17.01	17.10	.76						
		1.592			5.686			6.678			3.486			1.147			.310		
63.1 – 65.0		MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±	MEAN	MODE	S.D.±			
	22	12.94	12.76	.58	22 13.14	13.06	.61	22 13.45	13.46	.58	22 13.91	13.89	.71	22 14.49	13.71	.87	ALL DIMENSIONS		
	23	15.64	15.51	.91	23 16.61	16.41	1.06	23 17.40	17.26	1.06	23 18.30	18.15	1.11	23 19.44	19.29	1.11	ARE IN INCHES		
					24 41.35	41.03	1.21												
					25 16.67	16.86	.94												
		.959			2.367			2.167			1.086			.282					

not required, but is advisable in order to have experimental observations available to check the accuracy of the equations.

The third step is the calculation of regression equations showing the regression of a variable on stature and chest circumference. These equations are shown in Table 2. Concurrent with the third step is the

TABLE 2

Equations used for nomograph of Army men

S = Stature; Ch = Chest circumference

1. Sleeve length $= -.755 + .4026\,S + .1382\,Ch$
2. Inseam $= -3.909 + .5800\,S - .0830\,Ch$
3. Waist circumference $= 56.928 - .0089\,S - 2.3480\,Ch + .0451\,Ch^2$
4. Hip circumference $= 18.768 + .1290\,S - .1685\,Ch + .0116\,Ch^2$
5. Weight $= -11.951 + 2.3210\,S - 6.0380\,Ch + .1721\,Ch^2$
6. Cervicale height $= -4.724 + .9030\,S + .0464\,Ch$
7. Outseam $= -5.707 + .6810\,S + .0176\,Ch$
8. Lower leg length $= -2.507 + .2900\,S + .0150\,Ch$
9. *Wrist circumference $= 1.468 + .0263\,S + .0948\,Ch$
10. Total crotch length $= 33.616 + .2060\,S - .00067\,S^2 - 1.3070\,Ch + .0237\,Ch^2$
11. Crotch-thigh circumference $= 4.253 - .0305\,S + .5322\,Ch$
12. Bideltoid $= 3.571 + .0410\,S + .3210\,Ch$
13. Neck circumference $= 5.939 + .0164\,S + .2040\,Ch$
14. Cross back width $= 4.600 + .0157\,S + .2530\,Ch$
15. Vertical trunk circumference $= -21.394 + .4244\,S + 2.4311\,Ch - .0250\,Ch^2$
16. Sitting height $= 8.643 + .3776\,S + .0350\,Ch$
17. Trunk height $= 2.119 + .2750\,S + .0570\,Ch$
18. Patella height $= -2.538 + .3250\,S + .0540\,Ch$
19. Buttock-knee $= -1.891 + .3132\,S + .1060\,Ch$
20. Shoulder-elbow $= -.578 + .2056\,S + .0215\,Ch$
21. Forearm-hand length $= -.296 + .2520\,S + .0490\,Ch$
22. Hip breadth $= 13.397 + .0742\,S - .4600\,Ch + .0092\,Ch^2$
23. Elbow breadth $= 38.498 - 1.1070\,S + .0078\,S^2 + .5118\,Ch$
24. Shoulder circumference $= -194.561 + 6.0021\,S - .0423\,S^2 + .7080\,Ch$
25. Inside arm $= -1.443 + .3213\,S - .0764\,Ch$

* Not included on nomograph.

calculation of the standard error of estimate of the regression. The methods of calculation of regression equations and errors of estimate are adequately discussed in several textbooks of statistics.

Finally, having determined the regression slopes and shapes, the basic data can be used to locate the lines of relationship on the nomograph (Fig. 1). The detailed descriptions of the drawing of a nomograph may be obtained from several sources (Lipka, 1918; D'Ocagne, 1921).

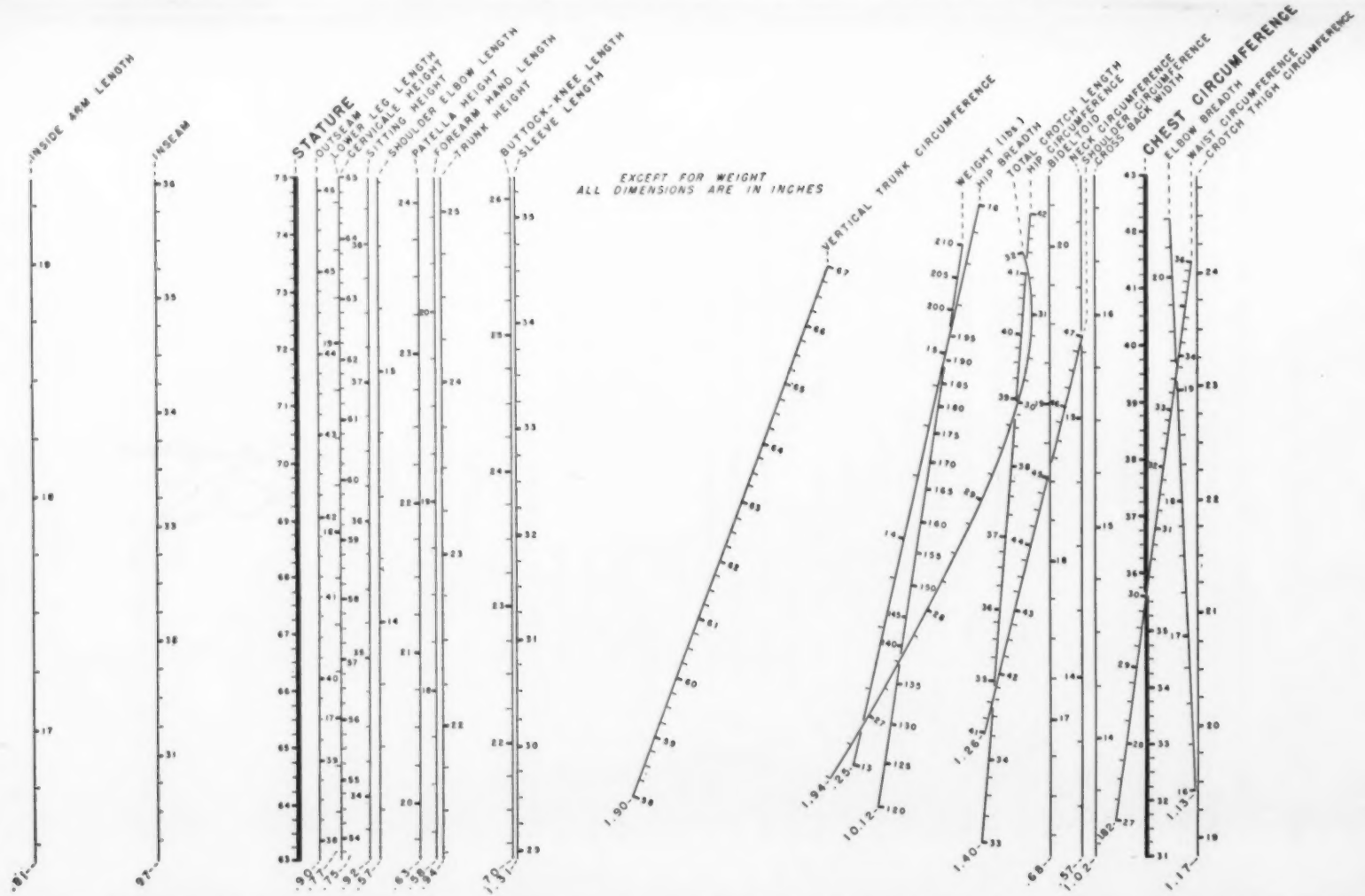

FIG. 1. ANTHROPOMETRIC NOMOGRAPH OF ARMY MEN. A straight line, passing through known values of stature and chest, will also pass through average values for all other dimensions as shown. Each average value thus indicated is mid-point of a range determined by adding and subtracting the amount shown below each line to the mid-point. This range will include about 70 per cent of men with the original given values of stature and chest.

Contrary to the usual scientific practice of all data remaining in the metric system, these data are presented in inches in order to facilitate the use of the nomograph by non-technical men.

DISCUSSION

With a nomograph at hand, several facts may be directly assessed. (1) The proportionate degree of correlation of a dependent variable to each of the independent variables. Those dimensions which lie closer to stature than to chest circumference are more highly related to stature than to the girth. The opposite is, of course, true for those lying closer to chest circumference. (2) A vertical line for the dimension indicates linear regression on both independent dimensions. (3) Dimensions *between* stature and chest are positively related to both. (4) Those dimensions *to the left* of stature decrease with increase in chest girth, and those *to the right* of chest circumference decrease with increase in stature. (5) A dimension sloping up and to the right, but straight, is linear in its regression on stature, but curvilinear in its regression on chest. A slope to the left, progressing upwards, would be the reverse. (6) A curved line indicates curvilinear regression on both independent variables.

The nomograph, then, provides a pictogram of a complex of variables, which may be subjectively studied to indicate generally the interrelationships present. Objectively studied, either as nomograph or as a series of equations, measures of likenesses or differences within and between populations may be determined.

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LATERAL DOMINANCE, CULTURE, AND WRITING SYSTEMS[1]

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THE primary purpose of this paper is to consider the relationship of lateral dominance (right- or left-handedness, eyedness, etc.) to manual and visual operations in various cultures, particularly those skills which are involved in reading and writing.

Nearly a century of study of lateral dominance by anatomists, physiologists, neurologists, psychologists, educators, and anthropologists has resulted in a voluminous literature on the subject. There has been, unfortunately, little agreement on fundamentals. Most anthropologists view the prevalence of right-handedness with confidence that it can be explained in terms of a dominant gene, determining hemisphere dominance.[2] Specialists in other fields discuss the question of the hereditary or cultural basis of lateral dominance with more caution,[3] and a recent study by a psychiatrist, Blau, interprets sinistrality as a symptom of an infantile psychoneurosis, a deviation from a merely culturally determined laterality.[4]

Fortunately, the genetic explanation of handedness is now on a fairly solid foundation, thanks to work in dermatoglyphics, in which significant correlations of finger and hand-print patterns with laterality, indicate, according to Cromwell and Rife,[5] "beyond any reasonable doubt the existence of an anatomical basis for functional handedness." The still more puzzling question of the ultimate evolutionary origin of lateral

[1] Read at the Toronto meeting of the American Anthropological Association, Dec. 30, 1948.

[2] Gillin, 1948: 105.

[3] Harris, 1948: 222-228.

[4] Blau, 1946: passim.

[5] Cromwell and Rife, 1942: 516-526. *Cf.* Rife and Schonfeld, 1944; Newman, 1934; Cummins, 1940; Rife, 1943. The original suggestion appeared in Bettman, 1932.

dominance, and the controversy concerning the occurrence or non-occurrence of preferred laterality in other species, are not settled by the dermatoglyphic demonstration of the anatomical basis for handedness, nor does this provide an answer to the problem of the priority of handedness over hemisphere laterality, or of the role of eyedness in the matter.

This paper, dealing mainly with writing, is not intended to shed much light on questions which involve the origin of handedness, which long antedates the invention of writing, an art limited to a brief fraction of the time of man's existence, and still confined to a few cultures, and within them, save in the last century, to a minority.

There is little doubt that most human beings in all cultures are right-handed and right-eyed; right-handedness seems to occur in from 90 per cent to 95 per cent of the populations so far tested by various observers. For preferred eyedness, the incidence of dextrality is less marked, more difficult to test or observe, and the eyes, moreover, are more likely to be affected by diseases and injuries which offset the original preferred laterality. There is no need here to do more than refer in passing to studies in non-literate cultures where handedness is revealed by ways of holding or using tools and weapons, dynamometer tests, methods of weaving, or basket making, by cultural expressions of the awkwardness of the left hand in terms of suspicion, evil omen, ridicule, or tabus upon its use for certain purposes (to say nothing of *required* use of the left hand for other purposes). We may assume that all cultures have been dominated by people who are dextral in their manual and probably in their visual skills, and that in all cultures where writing has been invented or to which it has been diffused, or where writing systems have been modified or changed, the techniques have been carried mainly by dextrals.

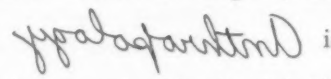
Of all the manual activities where specific right-hand preference is emphasized, writing is the most important and the one in which lack of what is called dexterity is most obvious in the result. True, certain weapons and tools, and more recently, some machines, must be designed for a particular hand, such as rifles or the Eskimo type of spearthrower. There are many manual activities of a fair degree of complexity where the hands perform tasks of unequal difficulty, as in basket-making, pottery-making, some kinds of weaving, carving, painting, etc., the non-preferred hand in such cases acting as a holder or steadier of the work or tool. Usually a sinistral individual can simply reverse the tasks of the two hands, or if this is inconvenient, train his non-preferred right hand to carry out the more skilled action. A pot, basket, or

textile made by a sinistral, provided he is skillful, may be superficially indistinguishable from one made by a dextral, even though the coils, twists, etc., may run clockwise instead of counter-clockwise, from right to left, or whatever may be the reverse of the procedure followed by dextrals. Writing, however, cannot be carried out in mirror-fashion and remain usable; a basket "made backwards" can still hold acorns, but backward writing imposes an intolerable burden on the normal reader who may seek to decipher it at all rapidly. The difference is not a matter of the small size of written symbols, even though most handwriting requires visual and motor coordinations accurate within a millimeter, nor of the complexity of the symbols altogether. Complexity does enter, however; a succession of stitches, knots, twists, or loops, as in an intricate textile or basket, does not have to be analyzed by the users of the finished artifact—the result is a pattern or surface or texture which can be appreciated without a systematic scanning of each tiny detail of the whole. The visual tasks involved in reading a page, scroll, or tablet covered with writing are of a different order. A page of an ordinary newspaper is made up of thousands of differentiated signs, each of which, while perhaps not read singly, is an essential part of a configuration of a word or group of three or four words. For the writing to have meaning, each of these clusters must be seen in sharp focus, and, what is very important, in the proper order (i. e. the order in which they were written).

All real writing systems, as distinguished from pictographic records or simple mnemonic devices such as quipus or prayer-beads, have arrangements of symbols in lines or columns, to be written and read successively from right to left, left to right, or alternately (boustrophedon), or vertically, from top to bottom, or rarely, from bottom to top.[6]

In nearly all writing systems, occasional deviations from the conventional order of symbols may occur, as in the curved or circular arrangement of legends on our coins. Further, most systems of writing permit a symbol or character to stand alone, outside of a text, as the letter *A* over a stadium tunnel, or an initial on a table napkin. Even here, of course, the isolated character or symbol must be presented in its conventional position or direction, with reference to right and left, or up and down.

[6] Diringer, 1948, has compiled a most comprehensive work on the writing systems of the world, ancient and modern. *Cf.* Mason, 1920.

In all systems of writing where texts of any length are found, consistent orientation of symbols is apparently required for quick perception as well as in the actual writing for reasonably accurate duplication of the conventional symbols. The writer and reader must not vacillate, shifting haphazardly from one direction to another, though in some monumental scripts, such as Egyptian hieroglyphic, there may be choice of three directions. Too frequent "reversals," either by writer or by reader in his perception or associations, result in confusion which lessens the effectiveness of communication. a ɒ t ⊏ rodoʅ o ƨy might be recognized by most readers of English, although with considerably diminished speed.  is far more difficult. The second is a complete reversal of horizontal direction, and is known as "mirror-writing," often considered an extreme symptom of reading and writing disability.

Much of the clinical interest in lateral dominance has arisen from studies of children who have difficulties in writing and reading, some of which seem to carry over into speech as stuttering or syllable transpositions (e. g., *intelligence* is pronounced *integillence*). There are investigators, like Blau, who interpret all such cases as environmental in origin, though related to lateral dominance, and others who relate functional writing and reading "disabilities" to *mixed* dominance (eyedness and handedness on opposite sides) or to *converted* dominance (left-handers forced to become right-handers). It is notable that in our literate culture, the "conversion" of left-handers is chiefly for writing skill. The only other strong motive for conversion to the prevailing dextrality is for skillful use of such artifacts as rifles, where the bolt is placed on the side most convenient for dextrals. In some athletic pursuits, sinistrality is a decided advantage (baseball, fencing, etc.).

It might be worth noting that certain recent mechanical inventions have relieved the writer of responsibility for directional and positional consistency in putting down symbols. The typewriter, monotype, linotype, stenotype, and single-key operated devices such as the telegraph, require merely that the sequence of symbols corrspond with the conventional sequence in time of words or phonetic elements of speech. The machine automatically takes care of the formation of the symbols (making the opening in the letter *C* face to the right, and so on), as well as their proper sequence and placement on a page or tape. These

innovations in writing do not relieve the reader of his responsibility to maintain a consistent direction or approach to the symbols with his eyes.

Another attribute of the reading skill might be mentioned: the very great speed with which adept readers (in many scripts, at least), can make the proper left to right, or right to left sequences of fixations, along with the lateral sweeps to succeeding lines, for many hours without perceptible fatigue.[7] There are other motor skills besides writing which are habitual, exceedingly rapid, and which can be repeated tens or hundreds of thousands of times, as in the making of fine basketry, but these operations lack the complex intellectual and emotional involvements of reading. Even speech, which requires very rapid motor adjustments in mouth and throat, does not proceed as fast as reading, which indeed utilizes the same motor patterns as speech, carried on subliminally, in addition to the ocular movements. A fast reader can maintain a rate of 400 words per minute for many hours, far faster than either the uttering or aural comprehension of speech.[8] Speech, moreover, while controlled by the dominant brain hemisphere, does not require unilateral or unidirectional movements (left to right or right to left); the shifts in tongue position, lip tension, vocal cord tension, etc., are mostly bilaterally symmetrical, carried on in the mid-line.

As stated previously, most humans are right-handed and right-eyed, which is another way of saying that they are left-hemisphered. The clinical studies of reading, writing, and certain kinds of functional speech disabilities have shown that there is "more than a chance relationship" between them and lateral dominance.[9] It is here, unfortunately, where nearly all of the students of the problem have fallen into what seems to the writer to be a serious error due to understandable ethnocentric bias, or perhaps ignorance of the reading habits in other literate cultures. Aside from a handful of students who have investigated eye-movements in reading Chinese,[10] chiefly between 1925 and 1935, the literature in Western languages on this subject not only tacitly but explicitly states that left-to-right eye-movements in reading and writing, and left-to-right hand movements (i. e. flexor movements of the right hand), are somehow "natural" or "normal" for the average

[7] Carmichael, 1948.

[8] Harris, 1948.

[9] Harris, 1948: 222-230.

[10] Miles and Shen, 1925; Chao, 1925; Chen and Carr, 1926; Shen, 1927; Tsai and Abernethy, 1928; Chou, 1929, 1930, 1935.

(dextral) human being. A corollary, seemingly well backed by clinical and scholastic evidence, is that the left-handed, the left-eyed, or persons with mixed or converted dominance, have difficulties in learning to read and write, arising from their "abnormal" tendencies to make leftward eye-movements, and leftward (extensor) movements if forced to use their right hands.

We have, in short, a respectable body of neurological [11] and another of psychiatric theory [12] which asserts that the natural or normal direction of writing (and reading) is from left to right, in horizontal lines which follow from top to bottom on a page. These theories go on to account for the phenomena of mirror-writing, of syllabic transpositions, and of speech defects such as stuttering, which are presumed to be limited to literate populations. Extensions of the same basic theory crop up in considerations of composition in art, which seek to demonstrate that Western or Occidental graphic art exhibits a tendency for action-patterns and directed gaze from left to right, in conformity with our writing and reading direction.

That there are and were peoples with writing conventionally written and read from right to left, as in Arabic and Hebrew, seems to be known to some of these students, but the facts are either ignored as of little theoretical interest, or they are made the basis of still other theories—for instance, that cultures with such "abnormal" writing directions are somehow introspective, contemplative, etc., in contrast to the situation where writing is directed outward, away from the median line, "towards ends and objects, away from the 'I'".[13] These theories recognize that peoples using right-to-left scripts are not predominantly left-handed; it is the right-handed who are "forced" to learn the unnatural medianward writing direction, and a similarly unnatural medianward succession of fixations of the eyes in reading. A recent syndicated news photograph of a trio of Yemenite Jews en route to Israel, shown reading the Bible in a camp near Aden, should be of interest here.[14] One of the three sits with the book in the regular position, so that he reads right to left in horizontal lines; another sits on the right side of the open book, so that he reads the Hebrew in vertical columns, upward, with the lines following from right to left,

[11] Dearborn and Leverett, 1945; Harris, 1948; Gillingham and Stillman, 1940.
[12] Blau, 1946.
[13] Keller, 1943: 1139-1142.
[14] Associated Press news photograph, April, 1949.

while the third sits on the left side of the book, reading in vertical columns downward, with the lines following left to right. Each, according to the caption, sits in the position in which he has *learned to read,* three (or four?) to a Bible, owing to the great scarcity of books in Yemen. Similar deviations from conventional directions have been reported from other areas where books are extremely scarce.

The literature on writing direction usually lumps Chinese and Japanese with Hebrew and Arabic as "ego-directed" scripts, though the former two, written and read in vertical columns, really have no more in common with the latter scripts than with those based on the Greek or Latin alphabets. The fact that most of the Indic scripts are written, like those of Europe, from left to right, is evidently unknown to those who generalize about "Asiatic" scripts.

Dearborn, whose theories stress motor activities in hand and coördinate binocular eye-movements, says it is easier for left-handers to move their left hands from right to left, and for the left-eyed to look (i. e. make a series of fixations) from right to left. Orton, whose theory is based on confusion of imagery among the right-hemisphered, the sinistrals, says that the left-sided will "naturally write mirror-writing," since the natural direction is from the median line outward, but he feels that sinistrals instructed in the dextrad writing would adapt themselves with no great difficulty.[15]

A brief consideration of the directional aspects of the world's scripts, past and present, shows that our convention is only one of several. The accompanying map (Fig. 1) gives the distribution of scripts, by direction of writing, for the period immediately prior to the vast overseas expansion of European culture after 1500 A. D. While left-to-right writing, arranged in lines following each other down the page may now be dominant, because of the vast expansion of literacy in Western countries, and the geographic spread of European cultures since 1500, it has not always been so. The pre-eminence of left-right scripts, numerically and geographically, is due to a combination of historical, economic, and religious factors altogether unrelated to the laterality aspects of the matter. The world's leading systems of writing are Latin, while Cyrillic, derived from Greek, Arabic, the Indic alphabets, and Chinese occupy decidedly subordinate positions at present.

The earliest existing texts in both Egypt and Mesopotamia are arranged in vertical columns read downward. In Egypt, the vertical

[15] Gillingham and Stillman, 1940.

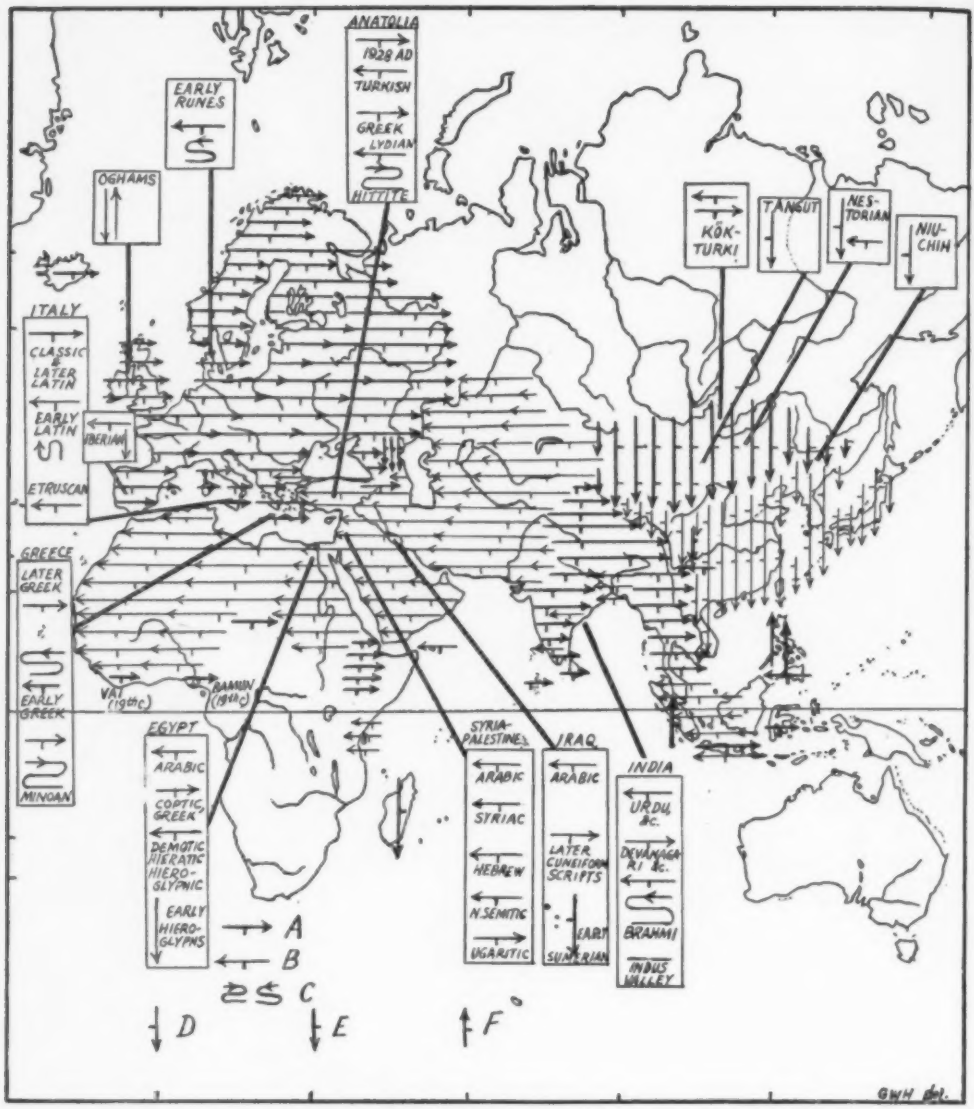


FIG. 1. DIRECTION OF PRINCIPAL SCRIPTS TO ABOUT 1500 A. D.

A. Left to right, downward, like English.
B. Right to left, downward, like Arabic and Hebrew.
C. Boustrophedon (alternate lines read in opposite directions).
D. Vertical, downward, columns right to left, like Chinese.
E. Vertical, downward, columns left to right, like Mongolian.
F. Vertical, upward, columns left to right, like Tagbánuwá.

NOTES: The cartouches show the directions of earlier scripts, now obsolete, or the sequence of writing directions in areas where there have been many changes, such as Egypt or Anatolia. The sequences in the cartouches are to be read upward, with the latest at the top.

Oceanian and American scripts not shown include: Easter Island (boustrophedon), Cuna of Panama (boustrophedon, but read upward), and Maya glyphs (usually read in pairs, left to right, downward).

Main sources: Diringer, 1948; Mason, 1920.

arrangement persisted on some monumental inscriptions, but was superseded for ordinary purposes by cursive scripts read in horizontal lines from right to left (hieractic and demotic). In Sumer, the writing shifted from vertical to horizontal, but the characters were read from left to right (as in English). The Mohenjo-Daro script of ancient India, possibly due to stimulus-diffusion from Mesopotamia, is, where preserved, in horizontal lines. Minoan was read left to right, and sometimes boustrophedon.[16] Chinese seems to have preferred vertical columns from the start, though the fact that the successive columns are arranged from the right to left has sometimes confused the issue. The strokes within the characters of Chinese (and the derivative Sino-Japanese) are always written from left to right; and in reading Chinese and Japanese, however the characters may be placed in lines or columns, the structure of the character requires a left-to-right "approach," even though this involves no eye-movement.

The map shows that Old World scripts have shifted from one direction or orientation to another, some from horizontal to vertical downward lines (Mongolian, Manchu), some from horizontal right to left, to vertical, and still others seem to have wavered back and forth. The only trends are clearly not trends in writing directions as such, but a gradual fixing of conventions because of the rise of world-religions demanding consistency in writing and reading of sacred texts. The religions most important in the fixing of writing directions seem to have been Buddhism, Confucianism, Judaism, Christianity, and Islam. Save for the recent Turkish abandonment of the Arabic script, there has been no consistent trend away from the supposedly abnormal right-to-left direction in writing by the literate of the Islamic world. The revival of Hebrew as a national language has made up for the default of Turkish from the lists of right-to-left scripts. The multiplication of writings based on the Latin alphabet in such areas as Negro Africa, and for the aboriginal peoples of the Americas and Oceania, has been the result of missionary zeal, and not of a natural triumph of a particular pattern of hand or eye dominance.

One significant fact does emerge from a consideration of the directional aspects of scripts assembled in Diringer's recent monumental work: the boustrophedon technique of writing and reading is seen to have been a short-lived one in all cases where evidence of it has been preserved. Evidently the writing of lines to be read alternately left-

[16] Diringer, 1948; Mason, 1920.

to-right and then right-to-left imposes too heavy a burden on writer and reader, particularly in cursive styles. Whenever a culture has experimented with boustrophedon, it has come out ultimately for a consistently unidirectional script. Boustrophedon inscriptions seem to belong uniformly to periods when writing was a novelty, practiced by a few adepts, and confined to occasional monumental texts, or to casual graffiti and the like.

The existence of *calligraphy* in scripts written in the three major directions—in derivatives of the Latin uncials, in Arabic, and in Chinese and Sino-Japanese—should have suggested to the students of eye-movements and hand-movements that writing can be carried out with apparently equal facility in any consistent direction. The lack of trends in script direction despite numerous shifts from vertical to horizontal, horizontal to vertical, and in laterality, during the last 3000-4000 years, should have merited the attention of the neurologists, psychiatrists, psychologists. and educators who have devoted themselves to reading and writing disabilities. The forms in which so-called "mirror-writing' manifests itself in such scripts as modern Hebrew and Yiddish, Arabic, Chinese, Japanese, Mongolian, or Korean, should surely have been examined.[17] What is the incidence of stuttering and reading disability (and are there any correlations?) among Japanese, or among the younger generation of modern Israel being brought up in a right-to-left writing tradition? Do left-handers find Hebrew or Arabic easier to write and read than the dextral majority, or does the imposition of dextrality on would-be sinistrals (with the use of the left hand being reserved for "unclean" activities) among the Arabs lead to confusion and frustration in any case?

Finally, the writer would like to see a full-scale attack on the problem of the relative reading efficiency of various directions for scripts, with a view to possible changes in our own conventions. Perhaps children

[17] In his 1947 fieldwork among the natives of Mindoro and Palawan, in the Philippines, Harold C. Conklin noted that left-hand writers among the Hanunóo and Buid of southern Mindoro use "an inverted 'mirror' style which causes the columns to progress from *right to left*." That such an instance of sinistral "mirror-writing" among primitive users of an Indic syllabary might not be cited to prove the neurological or psychological basis of inversions of conventional script directions, we must add that Conklin goes on to state that among the Tagbánuwá of central Palawan, whose script is essentially the same (i. e. an Indic syllabary, written and read in vertical columns upward, left to right), "left-handed, 'mirror' writing seems to have been quite unknown." Conklin, 1949: 269-271.

with ocular or motor disabilities (whether from mixed, confused, or converted hemispheric dominance) could be taught to read English, for instance, by turning the page so as to have the lines run in vertical columns. It should be obvious that the script itself imposes no particular orientation, as the Yemenite Bible-reading trio referred to above demonstrates. One need only to turn this page sideways, to see that it can be read with downward or vertical successions of fixations thus drastically reducing the most difficult of the ocular coordinations. In reading English as we ordinarily do, the two eyes are required to make unequal lateral deviations for each fixation, with three or more changes in parallax per line. The reader can easily test this upon another person by using the peephole technique of observing eye-movements, comparing the lateral fixations required in reading lines of horizontal writing with the even downward movements in vertical reading of the same material.[18] English read like Mongolian, in vertical lines, might be much easier, and could at least serve as a restful alternative reading technique. A moment's reflection will assure the skeptic that such a change in our conventional reading direction would not require any change in the existent books, periodicals, or other accumulated written records. The change would affect only the position in which the reader holds the page; the fact that our books are hinged at the sides rather than at the tops is no insurmountable burden to such a method. Many notebooks and workbooks even now are hinged along the page-top, and the slightly different motor pattern required in turning the pages has not led to a public outcry.

Many interesting ramifications of this subject remain to be investigated. Physical anthropologists might study the effects on reading and writing (if any) of differences in the horizontal plane of the eyes, the changes in the shape of the normal field of vision by the variations in the depth of the eye in the orbit, the elevation of the nasal bridge and tip, and possibly of the malars.[19] Is it merely historical accident that vertical scripts were started but abandoned in Egypt and Mesopotamia in favor of horizontal lines, whereas the Sinic culture has stuck to vertical scripts, and the Mongols and Manchus turned a horizontally-written alphabet into a vertical one? That writing materials have exercised an effect on script direction has been recognized: the

[18] Miles, 1928. Other methods of observing eye-movements without elaborate laboratory apparatus are described in such works as: Luckiesh and Moss, 1942; Betts, 1946; Stromberg, 1938.

[19] *Cf.* Newmayer, 1940.

curious vertical scripts of the Philippines seem to have developed as a result of the use of narrow bamboo strips as writing surfaces. Does the shape of the palpebral fissure affect the ease of reading horizontally?

This question was raised in a brief paper by Krogman on the anthropology of the eye, where reference was made to the belief that the relatively poor showing of Japanese wartime fighter-pilots was due to lack of training in the peripheral fields of vision (that is, the left and right portions of the periphery) because the Japanese were accustomed to read in vertical lines.[20] It should be noted that Krogman did not subscribe to such a theory, so far unsupported by good evidence, nor to the rumored hypertrophy of the superior and inferior rectus muscles for the same reason, among the Japanese. One wonders how the American (and other Western) pilots overcame the effects of a similar lack of training in the use of the same muscles, along with hypertrophy of the external and internal rectus muscles from reading English and other horizontal scripts.

In conclusion, it seems that neglect of extra-European cultural data, and of material on the history of writing generally, has vitiated much of the work of those engaged in the study of lateral dominance in relation to reading, writing, and speech disabilities. That there are connections between lateral dominance and mirror-writing is admitted, but until a careful check has been made among peoples who write and read consistently from right to left (i. e. in " mirror fashion " all the time, from our standpoint), present theories, whether neurological or psychiatric, are unproved. The need for cross-cultural testing of assumptions is as necessary in such a field as in the study of personality, as psychologists and psychiatrists have tardily come to realize.

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CORRELATIONS BETWEEN CERTAIN CRANIOFACIAL MEASUREMENTS, TRUNK LENGTH AND STATURE

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INTRODUCTION

THE object of this study is to discover if any degree of correlation exists between either stature or trunk length and the three-space dimensions of the cranium and the facial height.

The first international attempt at unifying craniometric and cephalometric measurements was made by the International Congress of Prehistoric Anthropology and Archeology (6), in Monaco, in 1906. This agreement was supplemented by another (6), in Geneva, in 1912.

Prior to this period and later, the literature reveals many studies that were undertaken to find any correlations between stature and the length of the long bones or between the different cranial dimensions. Among the leading authors who worked on the first phase, were Manouvrier (1893), Dwight (1894) and Topinard (1885). Even at the present day the tables of Manouvrier are still valuable. Among those who worked on the second phase is Cameron (3) (1927-1933), who made extensive craniometric studies chiefly concerning the intracranial correlations.

In 1929, Steggerda, Crane and Steel (12) carried out an extensive study of 100 measurements on 100 students, working out many correlations. In the same year Jackson (8) undertook a similar study on female students at the University of Minnesota.

The above-mentioned authors, and others, attacked the problem by taking the measurements on dried skulls or on living subjects, employing the same technique of measuring as approved by the International Congress. Later, we find individual attempts at revolutionizing the conventional methods. One of such attempts was that by Cameron (2) in presenting the "nasion-occipital length." He stated that this new

cranial measurement is "represented by a mesial line passing through the nasion parallel to the Frankfort plane."

Meanwhile, we find Todd (13), in 1928, trying to take advantage of the new inventions in measuring certain parts of the skeleton, such as the vertebral column, that could not be measured otherwise in the intact body. He took x-ray pictures of the vertebral column in dead bodies and compared measurements from them with those taken after dissection of the body and maceration of the column. In 1930 Ritt and Sawtell (11) made a similar study on certain bones of the arm.

In 1931 Broadbent (1) introduced a device which is a combination of a craniostat and an x-ray apparatus that allows placing of the head in a definite position while the roentgenogram is taken. This apparatus was used in the present study.

None of the above-mentioned studies was concerned with the correlations, if they exist, between stature and trunk length, on the one hand, and the three-space dimensions of the cranium and the facial height on the other. Lack of such data was recently felt by Dr. Otto F. Kampmeier in a case of skeletal and skull remains submitted to him by the Coroner's Office in Chicago for anthropological identification or clarification. Consequently, he suggested to the writer the desirability of undertaking the present study in order to add a further link in the chain of correlations worked out by the various authors mentioned. In that connection it was felt that since the Frankfort plane corresponds to the horizontal plane in the living subject, it is quite legitimate to use this plane as the base of reference for the different cranial and facial measurements, as will be explained later in Figs. 1 and 2.

MATERIAL AND METHODS

The documentary material for the present study was gathered by the author and consisted of the measurements of 200 individuals. Besides taking the standing- and sitting-heights, he made lateral and frontal x-ray pictures of the head (according to the Broadbent-Bolton technique), which were then traced and appraised. The series consisted of 200 human adults: 100 males and 100 females. Of the males, 2 were Mongolian and 1 Negro, and of the females, 4 were Negro and 1 Mongolian, while the rest of the two series were whites, representing a wide cross-section of the descendants of most, if not all, of the different Caucasian peoples of the world. Ages ranged in the male series from 20 to 57 years, and in the female, from 18 to 58 years.

Those anatomical landmarks, planes and measurements which pertain to the head (*cf.* Figs. 1 and 2) were located on the tracings of each lateral and frontal head plate.

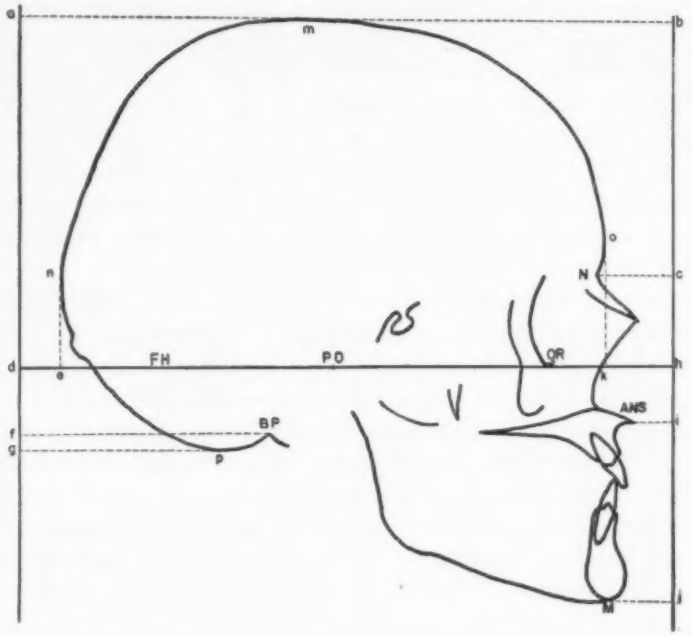

FIG. 1. OUTLINE DIAGRAM OF THE LATERAL VIEW OF THE SKULL TO INDICATE THE POSITIONS OF CERTAIN POINTS AND MEASUREMENTS

All straight, solid and dotted lines are either parallel or perpendicular to the Frankfort horizontal plane.

Po, porion; *OR*, orbitale; *N*, nasion; *ANS*, anterior nasal spine; *BP*, Bolton-point; *M*, menton; *FH*, Frankfort horizontal; *m*, the vertex; *o*, the most anterior point of the cranium; *n*, the most posterior point of the cranium; *p*, the most inferior point of the cranium; *e-k*, greatest cranial length; *a-g*, greatest cranial height; *a-f*, greatest Bolton-point-cranial height; *a-d*, greatest porion-cranial height; *b-j*, greatest skull height; *c-j*, facial height; *b-i*, greatest anterior nasal spine-cranial height.

Only linear measurements were used, since this study was concerned solely with finding the correlations, if such exist, between standing height and trunk length, on the one hand, and the three-space dimensions of the cranium and the facial height, on the other.

A lateral x-ray picture of the vertebral column would have been the best method of measuring its length instead of trunk length, taking into account its curvatures, but, because of the crowded conditions of the radiology department and the impossibility of providing separate equipment, the sitting-height was substituted and from it the cranial height was subtracted. Among the three different cranial heights

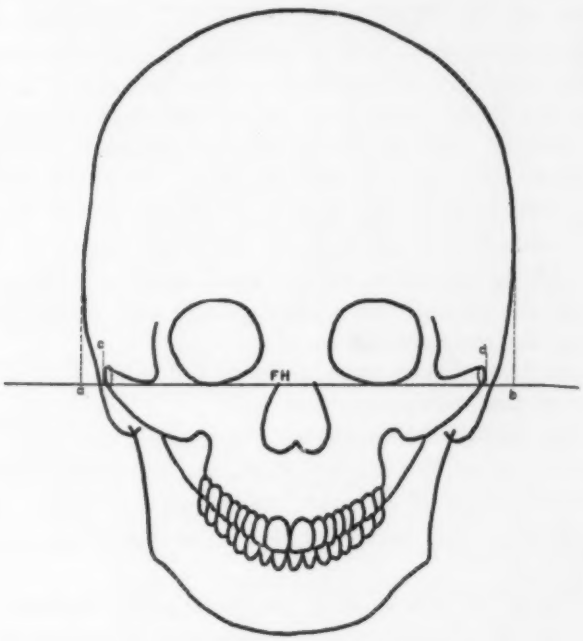

FIG. 2. OUTLINE DIAGRAM OF THE FRONTAL VIEW OF THE SKULL TO INDICATE THE POSITIONS OF CERTAIN POINTS AND MEASUREMENTS.

All straight, solid and dotted lines are either parallel or perpendicular to the Frankfort horizontal plane.

FH, Frankfort horizontal; *e and f*, the most lateral points of the cranium; *c and d*, the most lateral points of the zygomatic arches; *a-b*, greatest cranial breadth; *c-d*, greatest bizygomatic breadth.

measured in this study, the greatest Bolton-point cranial height (*cf.* Fig. 1) was chosen to obtain the trunk length, by subtracting it from the sitting height, for the Bolton point corresponds almost with the level of the upper surface at the atlas (highest point of the curvature behind occipital condyle.)

Stature and sitting-heights were measured on an anthropometer and the directions given to the subjects followed those of the international agreements, with a slight modification in regard to stature. For measuring the latter, the subject stands erect, on a level surface (floor), barefooted with heels togther, and with these, the buttocks and the shoulders applied to the vertical rod, while the head is held so that the visual as well as the biauricular axes are horizontal. The arms hang in a natural position. This is the method of Broca, which differs from the Geneva agreement in that it provides, through the application of the buttocks, shoulders, and the heels to the vertical rod, a standardized position, which is the method of the Geneva International agreement for sitting-height. For measuring the sitting-height, the subject sits on a horizontal and resisting seat, the knees are flexed, while the feet are placed upon a chair high enough to lift the dorsal muscles of the thigh from contact with the seat, so that they cannot be used by the subject in lifting the body. The dorsal aspect of the trunk makes contact with the vertical rod at two points, *viz.*, in the sacral region and between the shoulder blades.

Each tabulated figure for standing- and sitting-height represents the average of five readings.

The usual method of measuring the cranial and facial dimensions was not employed in this study; instead, the Frankfort-horizontal plane was taken as the base of reference, as indicated in Figs. 1 and 2, and the measurements were taken between lines parallel or perpendicular to that plane.

Correlational scales were used, on reading the measurements from the lateral and the frontal head-plate tracings, to correct the distortion caused by the radiating rays.

No attention was paid to the intracranial, intrafacial or cranio-facial correlations. The means, standard deviations, and coefficients of variation of all readings were determined and are tabulated in Table 1. All cranial and facial measurements were placed for correlation with stature and trunk length; all such correlations are recorded in Tables 2 and 3.

The terms applied to the different cranio-facial measurements are defined in Figs. 1 and 2.

FINDINGS

The means, standard deviations and coefficients of variation, with their standard errors, of the measurements of stature, trunk length, cranio-facial relations, and the facial height from the 100 males and

100 females are presented in Table 1. The tabulations of the correlations of stature, trunk length and the cranio-facial measurements are given in Tables 2 and 3.

TABLE 1

Means, standard deviations, and coefficients of variation, for certain measurements, with their standard errors, 100 males and 100 females

MEASUREMENT		MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION
Stature	*M*	175.52±.68	6.76±.48	3.85±.27
	F	163.24±.64	6.43±.45	3.94±.28
Trunk length	*M*	77.91±.28	2.78±.20	3.57±.25
	F	73.35±.27	6.66±.19	3.63±.26
Greatest cranial length	*M*	18.94±.27	0.62±.04	3.27±.23
	F	17.91±.06	0.64±.05	3.57±.25
Greatest cranial breadth	*M*	14.64±.06	0.62±.04	4.24±.30
	F	14.21±.05	0.53±.04	3.73±.26
Greatest cranial height	*M*	14.69±.05	0.52±.04	3.54±.25
	F	14.14±.05	0.49±.03	3.47±.25
Greatest Bolton-point cranial height	*M*	14.33±.05	0.52±.04	3.63±.26
	F	13.74±.05	0.49±.03	3.57±.25
Greatest porion-cranial height	*M*	12.57±.06	0.56±.04	4.46±.32
	F	11.93±.05	0.54±.04	4.53±.32
Greatest bizygomatic breadth	*M*	13.25±.05	0.54±.04	4.08±.29
	F	12.48±.04	0.43±.03	3.45±.24
Greatest vertical skull height	*M*	21.58±.08	0.80±.06	3.70±.26
	F	20.25±.09	0.85±.06	4.20±.30
Facial height	*M*	11.81±.06	0.59±.04	5.00±.35
	F	11.05±.06	0.61±.04	5.52±.39
Greatest anterior nasal spine-cranial height	*M*	15.06±.07	0.66±.05	4.40±.31
	F	14.12±.07	0.70±.05	4.95±.35

According to Fisher (5), "In testing the significance of an observed correlation we require to calculate the probability that such a correlation should arise, by random sampling, from an uncorrelated population. If the probability is low we regard the correlation as significant."

Accordingly, the correlations that presented a probability of .01 or less will be regarded as significant in this study.

DISCUSSION

Although the classical techniques used in anthropological measurements give very accurate results on dried skulls, their procedure is not adapted to the living subject due to the inaccessibility of many anthropological landmarks, in addition to the guess-work involved in computing the thickness of the soft tissues. These two obstacles were

TABLE 2

Correlations of the stature with the trunk length and the three-space dimensions of the cranium and the facial height for 100 males and 100 females

MEASUREMENTS CORRELATED WITH STATURE		COEFFICIENT OF CORRELATION	PROBABILITY
Trunk length	*M*	.712±.049	<.01
	F	.701±.051	<.01
Greatest cranial length	*M*	.283±.092	<.01
	F	.220±.095	>.02<.05
Greatest cranial breadth	*M*	.035±.100	>.10
	F	.071±.100	>.10
Greatest cranial height	*M*	.395±.084	<.01
	F	.290±.092	<.01
Greatest Bolton-point-cranial height	*M*	.355±.087	<.01
	F	.325±.089	<.01
Greatest porion-cranial height	*M*	.254±.094	=.01
	F	.310±.090	<.01
Greatest bizygomatic breadth	*M*	.295±.091	<.01
	F	.245±.094	>.01<.02
Greatest skull height	*M*	.335±.089	<.01
	F	.311±.090	<.01
Facial height	*M*	.295±.091	<.01
	F	.472±.078	<.01
Greatest anterior nasal spine-cranial height	*M*	.204±.096	>.02<.05
	F	.063±.100	>.10

overcome by using the x-ray approach which, in the author's opinion, gives more accurate results, provided correctional scales are used to correct the distortion caused by the radiating rays. By measuring the living animal by both methods, then sacrificing the animal to check both results, the reader will clarify any doubt in his mind concerning their accuracy.

To meet the second difficulty it was necessary to choose a method of measuring the three-space dimensions of the cranium and the facial height. The fact that so many different methods have been used to obtain such measurements could mean that no one has been found satisfactory enough to be accepted universally or to have served all purposes. Hence, the trial of an additional method is justified.

TABLE 3

Correlations of the vertebral length with the three-space dimensions of the cranium and the facial height for 100 males and 100 females

MEASUREMENTS CORRELATED WITH TRUNK LENGTH		COEFFICIENT OF CORRELATION	PROBABILITY
Greatest cranial length	*M*	.268±.093	<.01
	F	.222±.095	>.02<.05
Greatest cranial breadth	*M*	.255±.094	<.01
	F	.168±.097	>.05<.10
Greatest cranial height	*M*	.271±.093	<.01
	F	.246±.094	>.01<.02
Greatest Bolton-point-cranial height	*M*	.234±.095	>.01<.02
	F	.278±.092	<.01
Greatest porion-cranial height	*M*	.304±.091	<.01
	F	.143±.098	>.10
Greatest bizygomatic breadth	*M*	.326±.089	<.01
	F	.313±.090	<.01
Greatest skull height	*M*	.416±.083	<.01
	F	.320±.090	<.01
Facial height	*M*	.289±.092	<.01
	F	.360±.087	<.01
Greatest anterior nasal spine-cranial height	*M*	.301±.091	<.01
	F	.144±.098	>.10

An examination of Table 1 reveals that with three exceptions—namely, greatest cranial breadth, greatest cranial height, and greatest Bolton-point-cranial height, all of which showed a greater variation in the males—all the measurements varied more in the females. The facial height was the most variable, while the greatest cranial length was the least. Among the three cranial heights measured, the greatest porion-cranial height was the most variable, while the other two showed more or less the same degree of variability.

On studying Table 2, it was found that the correlation between stature and trunk length was rather high, a finding to be expected,

since the latter is a part of the former; yet, as shown in Table 1, trunk length constitutes only about 44 per cent of stature, thus making the correlation still significant.

This table reveals further that if we except the three correlations that stature shows respectively with greatest cranial breadth, greatest porion-cranial height, and greatest skull height—all of which correlations are higher in females—all other correlations are higher in the male. On comparing the correlations of stature with the three cranial heights employed—namely, (1) greatest cranial height, (2) greatest porion-cranial height, and (3) greatest Bolton-point-cranial height—the one involving the greatest cranial height was the highest in males. Although these three different measurements represent a part of stature, they constitute, as shown in Table 1, approximately only 8 per cent of it, a figure which does not account for the degree of correlation present. Consequently, these three correlations must be regarded as significant.

On examining Table 3, it is noted that with two exceptions—namely, those of trunk length with greatest Bolton-point-cranial height and with facial height, both of which exhibit a higher correlation in females than in males—all the correlations are higher in the males.

Among the correlations of trunk length with the three cranial heights taken, it was found that the greatest porion-cranial height showed the highest degree of correlation in the male.

On comparing Tables 2 and 3, we find that the facial height displays a higher correlation in females than in males. In both tables it is the highest correlation between stature and trunk length on the one hand, and the cranio-facial and facial measurements on the other. The greatest Bolton-point-cranial height reveals the best correlations, with both stature and with trunk length, of the three cranial heights measured.

A comparison of the correlations of breadth, length, and height of the cranium with stature and trunk length demonstrates that the last shows the highest correlation. Thus, it appears that the increase in size of the cranium which keeps pace to a certain extent with the increase in stature takes place principally in a vertical direction.

The greatest cranial breadth reveals hardly any degree of correlation with stature, while it shows a higher correlation with trunk length.

In answer to a possible criticism by the reader because of the inclusion of a few Negroes and Mongolians in the present study, it is obvious that this study is concerned with the correlations in the human species and not among its races. Even so, it appears from the few examples that neither one of these two groups indicated any appreciable differences

from the white population in this country, which in itself represents the descendants from most nations of the world.

In a recent meeting of pediatricians, a complaint was made regarding the lack of data concerning the different cranial and facial measurements exhibited by normal children at different ages. Were data of this kind available, together with such studies as the present one, they would furnish a standard by which abnormalities in growth could be detected before the condition became advanced. Thus by treating the disease in its infancy, great distortions in growth could be avoided in certain cases.

The significance of this study for the sculptor and the criminal anthropologist is evident.

SUMMARY

1. Stature, trunk length, and the three-space dimensions of the cranium and the facial height were taken on 200 adults, 100 males and 100 females.

2. The means, standard deviations, and coefficients of variation were calculated. The latter ranged from 3.27 for the greatest cranial length in males, to 5.52 for the facial height in females.

3. Correlations of stature with the different cranial and facial measurements are higher in the male, with two exceptions, namely, (1) stature and the greatest cranial breadth, and (2) stature and the facial height. The correlation between stature and trunk length, $.712 \pm .049$ in males, and $.701 \pm .051$ in females, is excellent.

4. Correlations of trunk length with the different cranial and facial measurements are higher in males, with two exceptions, namely, (1) trunk length and the greatest Bolton-point-cranial height, and (2) trunk length and the facial height.

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NOTES

WAR AND POSTWAR EXPERIENCE IN REGARD TO THE SEX RATIO AT BIRTH IN VARIOUS COUNTRIES *

A VERY interesting demographic sidelight is the sex ratio at birth (ratio of male births to female births). This subject is of considerable popular interest, and it is widely thought that during wars relatively more boys are born than in normal times when the ratio is usually about 1050 to 1060 boy babies for every 1000 girl babies.

In a previous paper (1) the author has pointed out for the United States the experience during the war years, indicating only a very slight increase in the sex ratio at birth. This difference was indicated to be statistically significant since the sex ratio at birth has over the past been a constant, unchanging item (2). But from the layman's viewpoint there was no evidence of any appreciable increase in masculinity of births since the excess of actual over expected male births for 1942-45 was only about 6500 out of total births of 11¼ million, or, in other words, an excess of only 0.1 per cent relatively.

The current paper analyzes the sex ratio at birth for various countries for the prewar period 1931-40, the war period 1941-45, and the postwar period 1946-47. The countries included are the United States, Great Britain, Canada, Australia, and New Zealand, for all of which up-to-date accurate data are available.

Table 1 presents the total births in various periods and the sex ratio of these births, namely, the number of male births per 1000 female births. Without any detailed statistical analysis, it will be seen that with but one exception—Australia—the sex ratio was higher for each country during the war period than in the prewar period, although the differential involved was in all instances relatively small, the greatest difference being less than 1 per cent.

* Any opinions expressed in this paper are those of the author and bear no relation to his work with the Social Security Administration.

Next, comparing the war experience with that during the two postwar years for which data are available, it may be noted that there is some indication of an even higher sex ratio at birth in the postwar period in the United States, and especially in Australia. In England and Wales the postwar sex ratio, although having fallen off slightly, is still definitely above the prewar level, while for Canada and New Zealand there seems to be no appreciable difference as between prewar and postwar years.

TABLE 1

Numbers and sex ratios of births for various countries, 1931-47

PERIOD	UNITED STATES	ENGLAND AND WALES	CANADA	AUSTRALIA	NEW ZEALAND
		Total births [a]			
1931-35	10 590 775	3 022 864	1 141 765	561 510	124 127
1936-40	11 261 076	3 041 652	1 143 835	604 860	139 704
1941-45	13 787 539	3 346 343	1 384 160	734 432	169 591
1946	3 288 672	820 719	330 732	176 379	41 871
1947 [b]	3 699 940	881 026	359 303	182 384	44 816
1931-47	42 628 002	11 112 604	4 359 795	2 259 565	520 109
		Sex ratio (Males per 1000 females)			
1931-35	1054	1051	1053	1052	1060
1936-40	1053	1054	1055	1050	1042
1941-45	1056	1062	1062	1051	1057
1946	1059	1060	1057	1065	1059
1947 [b]	1055	1061	1051	1059	1045
1931-47	1055	1057	1057	1053	1053

[a] Reported births, not including any allowance for unregistered births.

[b] Some figures for 1947 are preliminary and subject to slight revision, but this should have little, if any, effect on the sex ratio.

It is interesting to note that for the countries studied, there is such little difference in the sex ratio as between countries for the entire 17-year period studied. Thus the range in the sex ratio for the five countries was only from 1053 to 1057, or less than 0.5 per cent.

Part of the higher sex ratio in the postwar years in the United States may be attributable to a greater number of first births, which generally have shown a higher sex ratio. It is more likely, however, that this rise may be part of a change in the general level of the sex ratio at birth.

A recent study (3) has suggested that the long-term decrease in the proportion of stillbirths apparently has resulted in an increase in the sex ratio at birth. This is altogether reasonable since the sex ratio of stillbirths is so high (roughly, 1200 to 1300 males per 1000 females), and so, as an increasing proportion of stillbirths is prevented, there will be a slightly larger proportion of male births. On the other hand, it should be mentioned that Tietze (4) has seriously questioned whether the official statistics showing a high sex ratio for stillbirths are correct.

The Metropolitan study (3) also confirms the findings of the present paper, namely, that there is no evidence in recent experience of the United States that boy babies increase significantly during war and immediate postwar periods.

In summary, this paper indicates:

1. The sex ratio at birth did not increase appreciably during the war years as compared with the years immediately preceding and following, not only for the United States but also for a number of other countries with good data.

2. The sex ratio at birth varies but little as between the various English-speaking countries studied.

3. There is some indication of a slight secular trend in the sex ratio at birth which bears further study and investigation.

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